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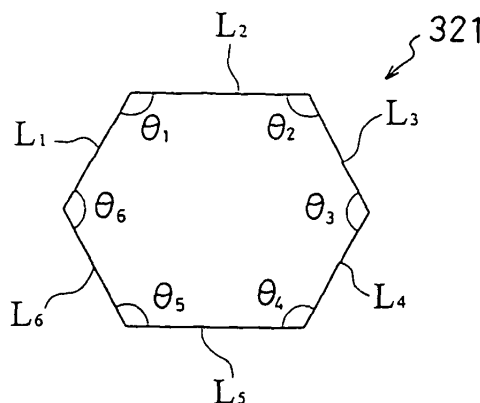
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(54) **Ink-jet head and ink-jet printer**

(57) An ink-jet head comprises a passage unit including pressure chambers each having one end connected with a nozzle and the other end to be connected with an ink supply source. The pressure chambers are arranged along a plane to neighbor each other. The ink-jet head further comprises actuator units fixed to a surface of the passage unit for changing the volume of each pressure chamber. Each actuator unit includes pressure generation portions respectively corresponding to pressure chambers, and is formed to extend over the pressure chambers. The actuator units are arranged along

the longitudinal direction of the passage unit so that each neighboring actuator units partially overlap each other in the lateral direction of the passage unit. Each actuator unit has a basic region where many pressure generation portions are formed in a matrix, and an additional region neighboring the basic region in the lateral direction of the passage unit. In the additional region, pressure generation portions are formed to correspond to a gap portion between the pressure generation portions in the basic region of the actuator unit and the pressure generation portions in the basic region of another actuator unit neighboring that actuator unit.

FIG. 28A



Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an ink-jet head for printing by ejecting ink onto a print medium, and to an ink-jet printer having the ink-jet head.

2. Description of Related Art

[0002] In an ink-jet printer, an ink-jet head distributes ink, which is supplied from an ink tank, to pressure chambers. The ink-jet head selectively applies pressure to each pressure chamber to eject ink through a nozzle. As a means for selectively applying pressure to the pressure chambers, an actuator unit may be used in which ceramic piezoelectric sheets are laminated.

[0003] As an example, an ink-jet head of that kind is known having one actuator unit in which continuous flat piezoelectric sheets extending over a plurality of pressure chambers are laminated and at least one of the piezoelectric sheets is sandwiched by a common electrode common to many pressure chambers and being kept at the ground potential, and many individual electrodes, i.e., driving electrodes, disposed at positions corresponding to the respective pressure chambers (refer to US Pat. No.5,402,159). The part of piezoelectric sheet being sandwiched by the individual and common electrodes and polarized in its thickness is expanded or contracted in its thickness direction as an active layer, by the so-called longitudinal piezoelectric effect, when a individual electrode on one face of the sheet is set at a different potential from that of the common electrode on the other face. The volume of the corresponding pressure chamber thereby changes, so ink can be ejected toward a print medium through a nozzle communicating with the pressure chamber.

[0004] In such an ink-jet head, to ensure good ink ejection performance, the actuator unit must be accurately positioned to a passage unit so that the individual electrodes must be at predetermined positions corresponding to the respective pressure chambers in a plan view.

[0005] In many cases, such an ink-jet head as described above is manufactured in the following manner because of various restrictions on manufacture. That is, the passage unit in which ink passages including pressure chambers have been formed is manufactured separately from the actuator unit. The passage unit is then bonded with an adhesive to the actuator unit so that the pressure chambers be close to the actuator unit. This bonding process is done as a mark formed on the passage unit is made to coincide with a mark formed on the actuator unit.

[0006] In general, however, the piezoelectric sheets of the actuator unit are manufactured through a sintering

process while the passage unit is laminated with metallic sheets. Therefore, the larger the size of the piezoelectric sheets is, the lower the positional accuracy of the electrodes is. Thus, the longer the head is, the more the positioning process is difficult between the pressure chambers in the passage unit and the individual electrodes in the actuator unit. As a result, the manufacture yield of heads may be lowered.

[0007] On the other hand, the actuator unit is an expensive minute component and it is very brittle because it is made of ceramic. Particularly in the actuator unit having a polygonal shape, its corners are very easy to be broken off. The break loss is a cause of an increase in manufacture cost. Besides, very delicate handling of the actuator unit is required such that any corner must not collide against another component. This makes it difficult to assemble the ink-jet head.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide an ink-jet head in which an actuator unit has been accurately positioned to a passage unit.

[0009] Another object of the present invention is to provide an ink-jet head in which an actuator unit is hard to be broken.

[0010] According to one aspect of the present invention provided is an ink-jet head comprising a passage unit including a plurality of pressure chambers each having one end connected with a nozzle and the other end to be connected with an ink supply source. The plurality of pressure chambers are arranged along a plane to neighbor each other. The ink-jet head further comprises actuator units fixed to a surface of the passage unit for changing the volume of each pressure chamber. Each actuator unit includes pressure generation portions respectively corresponding to pressure chambers. Each actuator unit is formed to extend over the pressure chambers. The actuator units are arranged along the longitudinal direction of the passage unit so that each neighboring actuator units partially overlap each other in the lateral direction of the passage unit. Each actuator unit comprises a basic region where a large number of pressure generation portions are formed in a matrix, and an additional region neighboring the basic region in the lateral direction of the passage unit. In the additional region, pressure generation portions are formed to correspond to a gap portion between the pressure generation portions in the basic region of the actuator unit and the pressure generation portions in the basic region of another actuator unit neighboring that actuator unit. The present invention provides also an ink-jet printer having the ink-jet head.

[0011] In this construction, each of the actuator units can be positioned to the passage unit independently of each other. Therefore, even in case of a long head, the increase in positional shift between electrode and pressure chamber of each actuator unit can be suppressed.

Thus, both can accurately be positioned to each other. As a result, good ink ejection performance can be obtained and the manufacture yield of heads is improved. In addition, since the pressure generation portions in the additional region provided in an actuator unit correspond to the gap portion between them and the pressure generation portions in the basic region of a neighboring actuator unit, the number of pressure generation portions can not be made small in the vicinity of the seam portion between the actuator unit and the neighboring actuator unit. Therefore, a head can be obtained in which there is substantially no variation in the number of pressure generation portions along the longitudinal direction of the passage unit.

[0012] According to another aspect of the present invention provided is an ink-jet head comprising a passage unit including pressure chambers each communicating with a nozzle for ejecting ink. The plurality of pressure chambers are arranged along a plane to neighbor each other. The ink-jet head further comprises an actuator unit fixed to a surface of the passage unit for changing the volume of each pressure chamber. The actuator unit is formed to extend along the pressure chambers. The actuator unit includes pressure generation portions corresponding to the respective pressure chambers. The actuator unit has its profile with five or more straight portions. Each straight portion is connected with a neighboring straight portion at the right angle or an obtuse angle.

[0013] In this feature, by making any corner of the actuator unit into the right angle or an obtuse angle, the actuator unit is hard to be broken upon manufacturing the ink-jet head.

[0014] According to further another aspect of the present invention provided is an ink-jet head comprising a passage unit including a plurality of pressure chambers each communicating with a nozzle for ejecting ink. The plurality of pressure chambers are arranged along a plane to neighbor each other. The ink-jet head further comprises a plurality of actuator units arranged along the longitudinal direction of the passage unit and fixed to a surface of the passage unit for changing the volume of each of the pressure chambers. Each of the actuator units includes a plurality of pressure generation portions respectively corresponding to pressure chambers. Each of the actuator units is formed to extend over the pressure chambers.

[0015] In this construction, each of the actuator units can be positioned to the passage unit independently of each other. Therefore, even in case of a long head, the increase in positional shift between electrode and pressure chamber of each actuator unit can be suppressed. Thus, both can accurately be positioned to each other. As a result, good ink ejection performance can be obtained and the manufacture yield of heads is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Other and further objects, features and advantages of the invention will appear more fully from the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a general view of an ink-jet printer including ink-jet heads according to a first embodiment of the present invention;

FIG. 2 is a perspective view of an ink-jet head according to a first embodiment of the present invention;

FIG. 3 is a sectional view taken along line III-III in FIG. 2;

FIG. 4 is a plan view of a head main body included in the ink-jet head of FIG. 2;

FIG. 5 is an enlarged view of the region enclosed with an alternate long and short dash line in FIG. 4;

FIG. 6 is an enlarged view of the region enclosed with an alternate long and short dash line in FIG. 5;

FIG. 7 is a partial sectional view of the head main body of FIG. 4;

FIG. 8 is an enlarged view of the region enclosed with an alternate long and two short dashes line in FIG. 5;

FIG. 9 is a partial exploded view of the head main body of FIG. 4;

FIG. 10 is an enlarged sectional view when laterally viewing the region enclosed with an alternate long and short dash line in FIG. 7;

FIG. 11 is a plan view of a head main body included in an ink-jet head according to a second embodiment of the present invention;

FIG. 12 is a bottom view of the head main body of FIG. 11;

FIG. 13 is a cross-sectional view of the head main body of FIG. 11;

FIG. 14 is an enlarged view of the region Q enclosed with an alternate long and short dash line in FIG. 13;

FIG. 15 is a partial sectional view of the head main body of FIG. 11;

FIG. 16 is an enlarged sectional view illustrating the detailed construction of an actuator unit in the head main body of FIG. 11;

FIG. 17 is an enlarged plan view of an actuator unit in the head main body of FIG. 11;

FIG. 18 is an enlarged plan view showing a seam portion between two actuator units of FIG. 17;

FIG. 19 is an enlarged plan view of an actuator unit according to a modification of a second embodiment of the present invention;

FIG. 20 is an enlarged plan view showing a seam portion between two actuator units of FIG. 19;

FIG. 21A is a plan view of a head main body included in an ink-jet head according to a modification of the second embodiment, in which four actuator units are arranged;

FIG. 21B is a plan view of a head main body included in an ink-jet head according to another modification of the second embodiment, in which four actuator units are arranged;

FIG. 22 is a plan view of a head main body included in an ink-jet head according to a third embodiment of the present invention;

FIG. 23 is a bottom view of the head main body of FIG. 22;

FIG. 24 is a cross-sectional view of the head main body of FIG. 22;

FIG. 25 is an enlarged view of the region E enclosed with an alternate long and short dash line in FIG. 24;

FIG. 26 is a partial sectional view of the head main body of FIG. 22;

FIG. 27 is an enlarged sectional view illustrating the detailed construction of an actuator unit in the head main body of FIG. 22;

FIG. 28A is a schematic view illustrating the profile of an actuator unit included in the head main body of FIG. 22;

FIG. 28B is a schematic view illustrating the profile of an actuator unit as a modification;

FIG. 29A is a plan view of a modification of the head main body of FIG. 22, which includes heptagonal actuator units;

FIG. 29B is a plan view of an actuator unit included in the head main body of FIG. 29A;

FIG. 30A is a plan view of another modification of the head main body of FIG. 22, which includes octagonal actuator units;

FIG. 30B is a plan view of an actuator unit included in the head main body of FIG. 30A;

FIG. 31A is a plan view of still another modification of the head main body of FIG. 22, which includes partially rounded actuator units;

FIG. 31B is a plan view of an actuator unit included in the head main body of FIG. 31A; and

FIG. 32 is a schematic view of a principal part of an ink-jet printer according to the fourth embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] First, an ink-jet head as a reference for understanding ink-jet heads according to embodiments of the present invention will be described with reference to FIGS. 1 to 10. FIG. 1 is a general view of an ink-jet printer including ink-jet heads according to a first embodiment of the present invention. The ink-jet printer 101 as illustrated in FIG. 1 is a color ink-jet printer having four ink-jet heads 1. In this printer 101, a paper feed unit 111 and a paper discharge unit 112 are disposed in left and right portions of FIG. 1, respectively.

[0018] In the printer 101, a paper transfer path is provided extending from the paper feed unit 111 to the paper discharge unit 112. A pair of feed rollers 105a and

105b is disposed immediately downstream of the paper feed unit 111 for pinching and putting forward a paper as an image record medium. By the pair of feed rollers 105a and 105b, the paper is transferred from the left to the right in FIG. 1. In the middle of the paper transfer path, two belt rollers 106 and 107 and an endless transfer belt 108 are disposed. The transfer belt 108 is wound on the belt rollers 106 and 107 to extend between them. The outer face, i.e., the transfer face, of the transfer belt 108 has been treated with silicone. Thus, a paper fed through the pair of feed rollers 105a and 105b can be held on the transfer face of the transfer belt 108 by the adhesion of the face. In this state, the paper is transferred downstream (rightward) by driving one belt roller 106 to rotate clockwise in FIG. 1 (the direction indicated by an arrow 104).

[0019] Pressing members 109a and 109b are disposed at positions for feeding a paper onto the belt roller 106 and taking out the paper from the belt roller 106, respectively. Either of the pressing members 109a and 109b is for pressing the paper onto the transfer face of the transfer belt 108 so as to prevent the paper from separating from the transfer face of the transfer belt 108. Thus, the paper surely adheres to the transfer face.

[0020] A peeling device 110 is provided immediately downstream of the transfer belt 108 along the paper transfer path. The peeling device 110 peels off the paper, which has adhered to the transfer face of the transfer belt 108, from the transfer face to transfer the paper toward the rightward paper discharge unit 112.

[0021] Each of the four ink-jet heads 1 has, at its lower end, a head main body 1a. Each head main body 1a has a rectangular section. The head main bodies 1a are arranged close to each other with the longitudinal axis of each head main body 1a being perpendicular to the paper transfer direction (perpendicular to FIG. 1). That is, this printer 101 is a line type. The bottom of each of the four head main bodies 1a faces the paper transfer path. In the bottom of each head main body 1a, a number of nozzles are provided each having a small-diameter ink ejection port. The four head main bodies 1a eject ink of magenta, yellow, cyan, and black, respectively.

[0022] The head main bodies 1a are disposed such that a narrow clearance is formed between the lower face of each head main body 1a and the transfer face of the transfer belt 108. The paper transfer path is formed within the clearance. In this construction, while a paper, which is being transferred by the transfer belt 108, passes immediately below the four head main bodies 1a in order, the respective color inks are ejected through the corresponding nozzles toward the upper face, i.e., the print face, of the paper to form a desired color image on the paper.

[0023] The ink-jet printer 101 is provided with a maintenance unit 117 for automatically carrying out maintenance of the ink-jet heads 1. The maintenance unit 117 includes four caps 116 for covering the lower faces of the four head main bodies 1a, and a not-illustrated purge

system.

[0024] The maintenance unit 117 is at a position immediately below the paper feed unit 111 (withdrawal position) while the ink-jet printer 101 operates to print. When a predetermined condition is satisfied after finishing the printing operation (for example, when a state in which no printing operation is performed continues for a predetermined time period or when the printer 101 is powered off), the maintenance unit 117 moves to a position immediately below the four head main bodies 1a (cap position), where the maintenance unit 117 covers the lower faces of the head main bodies 1a with the respective caps 116 to prevent ink in the nozzles of the head main bodies 1a from being dried.

[0025] The belt rollers 106 and 107 and the transfer belt 108 are supported by a chassis 113. The chassis 113 is put on a cylindrical member 115 disposed under the chassis 113. The cylindrical member 115 is rotatable around a shaft 114 provided at a position deviating from the center of the cylindrical member 115. Thus, by rotating the shaft 114, the level of the uppermost portion of the cylindrical member 115 can be changed to move up or down the chassis 113 accordingly. When the maintenance unit 117 is moved from the withdrawal position to the cap position, the cylindrical member 115 must have been rotated at a predetermined angle in advance so as to move down the transfer belt 108 and the belt rollers 106 and 107 by a pertinent distance from the position illustrated in FIG. 1. A space for the movement of the maintenance unit 117 is thereby ensured.

[0026] In the region surrounded by the transfer belt 108, a nearly rectangular parallelepiped guide 121 (having its width substantially equal to that of the transfer belt 108) is disposed at an opposite position to the ink-jet heads 1. The guide 121 is in contact with the lower face of the upper part of the transfer belt 108 to support the upper part of the transfer belt 108 from the inside.

[0027] Next, the construction of each ink-jet head 1 according to this embodiment will be described in more detail. FIG. 2 is a perspective view of the ink-jet head 1. FIG. 3 is a sectional view taken along line III-III in FIG. 2. Referring to FIGS. 2 and 3, the ink-jet head 1 according to this embodiment includes a head main body 1a having a rectangular shape in a plan view and extending in one direction (main scanning direction), and a base portion 131 for supporting the head main body 1a. The base portion 131 supporting the head main body 1a further supports thereon driver ICs 132 for supplying driving signals to individual electrodes 35a and 35b (see FIG. 6 and FIG. 10), and substrates 133.

[0028] Referring to FIG. 2, the base portion 131 is made up of a base block 138 partially bonded to the upper face of the head main body 1a to support the head main body 1a, and a holder 139 bonded to the upper face of the base block 138 to support the base block 138. The base block 138 is a nearly rectangular parallelepiped member having substantially the same length of the head main body 1a. The base block 138 made of

metal material such as stainless steel has a function as a light structure for reinforcing the holder 139. The holder 139 is made up of a holder main body 141 disposed near the head main body 1a, and a pair of holder support portions 142 each extending on the opposite side of the holder main body 141 to the head main body 1a. Each holder support portion 142 is as a flat member. These holder support portions 142 extend along the longitudinal direction of the holder main body 141 and are disposed in parallel with each other at a predetermined interval.

[0029] Skirt portions 141a in a pair, protruding downward, are provided in both end portions of the holder main body 141a in a sub scanning direction (perpendicular to the main scanning direction). Either skirt portion 141a is formed through the length of the holder main body 141. As a result, in the lower portion of the holder main body 141, a nearly rectangular parallelepiped groove 141b is defined by the pair of skirt portions 141a. The base block 138 is received in the groove 141b. The upper surface of the base block 138 is bonded to the bottom of the groove 141b of the holder main body 141 with an adhesive. The thickness of the base block 138 is somewhat larger than the depth of the groove 141b of the holder main body 141. As a result, the lower end of the base block 138 protrudes downward beyond the skirt portions 141a.

[0030] Within the base block 138, as a passage for ink to be supplied to the head main body 1a, an ink reservoir 3 is formed as a nearly rectangular parallelepiped space (hollow region) extending along the longitudinal direction of the base block 138. In the lower face 145 of the base block 138, openings 3b (see FIG. 4) are formed each communicating with the ink reservoir 3. The ink reservoir 3 is connected through a not-illustrated supply tube with a not-illustrated main ink tank (ink supply source) within the printer main body. Thus, the ink reservoir 3 is suitably supplied with ink from the main ink tank.

[0031] In the lower face 145 of the base block 138, the vicinity of each opening 3b protrudes downward from the surrounding portion. The base block 138 is in contact with a passage unit 4 (see FIG. 3) of the head main body 1a at the only vicinity portion 145a of each opening 3b of the lower face 145. Thus, the region of the lower face 145 of the base block 138 other than the vicinity portion 145a of each opening 3b is distant from the head main body 1a. Actuator units 21 are disposed within the distance.

[0032] To the outer side face of each holder support portion 142 of the holder 139, a driver IC 132 is fixed with an elastic member 137 such as a sponge being interposed between them. A heat sink 134 is disposed in close contact with the outer side face of the driver IC 132. The heat sink 134 is made of a nearly rectangular parallelepiped member for efficiently radiating heat generated in the driver IC 132. A flexible printed circuit (FPC) 136 as a power supply member is connected with

the driver IC 132. The FPC 136 connected with the driver IC 132 is bonded to and electrically connected with the corresponding substrate 133 and the head main body 1a by soldering. The substrate 133 is disposed outside the FPC 136 above the driver IC 132 and the heat sink 134. The upper face of the heat sink 134 is bonded to the substrate 133 with a seal member 149. Also, the lower face of the heat sink 134 is bonded to the FPC 136 with a seal member 149.

[0033] Between the lower face of each skirt portion 141a of the holder main body 141 and the upper face of the passage unit 4, a seal member 150 is disposed to sandwich the FPC 136. The FPC 136 is fixed by the seal member 150 to the passage unit 4 and the holder main body 141. Therefore, even if the head main body 1a is elongated, the head main body 1a can be prevented from being bent, the interconnecting portion between each actuator unit and the FPC 136 can be prevented from receiving stress, and the FPC 136 can surely be held.

[0034] Referring to FIG. 2, in the vicinity of each lower corner of the ink-jet head 1 along the main scanning direction, six protruding portions 30a are disposed at regular intervals along the corresponding side wall of the ink-jet head 1. These protruding portions 30a are provided at both ends in the sub scanning direction of a nozzle plate 30 in the lowermost layer of the head main body 1a (see FIGS. 7A and 7B). The nozzle plate 30 is bent by about 90 degrees along the boundary line between each protruding portion 30a and the other portion. The protruding portions 30a are provided at positions corresponding to the vicinities of both ends of various papers to be used for printing. Each bent portion of the nozzle plate 30 has a shape not right-angled but rounded. This makes it hard to bring about clogging of a paper, i.e., jamming, which may occur because the leading edge of the paper, which has been transferred to approach the head 1, is stopped by the side face of the head 1.

[0035] FIG. 4 is a schematic plan view of the head main body 1a. In FIG. 4, an ink reservoir 3 formed in the base block 138 is imaginarily illustrated with a broken line. Referring to FIG. 4, the head main body 1a has a rectangular shape in the plan view extending in one direction (main scanning direction). The head main body 1a includes a passage unit 4 in which a large number of pressure chambers 10 and a large number of ink ejection ports 8 at the front ends of nozzles (as for both, see FIGS. 5, 6, and 7), as described later. Trapezoidal actuator units 21 arranged in two lines in a zigzag manner are bonded onto the upper face of the passage unit 4. Each actuator unit 21 is disposed such that its parallel opposed sides (upper and lower sides) extend along the longitudinal direction of the passage unit 4. The oblique sides of each neighboring actuator units 21 overlap each other in the lateral direction of the passage unit 4.

[0036] The lower face of the passage unit 4 corresponding to the bonded region of each actuator unit 4

is made into an ink ejection region. In the surface of each ink ejection region, a large number of ink ejection ports 8 are arranged in a matrix, as described later. In the base block 138 disposed above the passage unit 4, an ink reservoir 3 is formed along the longitudinal direction of the base block 138. The ink reservoir 3 communicates with an ink tank (not illustrated) through an opening 3a provided at one end of the ink reservoir 3, so that the ink reservoir 3 is always filled up with ink. In the ink reservoir 3, pairs of openings 3b are provided in regions where no actuator unit 21 is present, so as to be arranged in a zigzag manner along the longitudinal direction of the ink reservoir 3.

[0037] FIG. 5 is an enlarged view of the region enclosed with an alternate long and short dash line in FIG. 4. Referring to FIGS. 4 and 5, the ink reservoir 3 communicates through each opening 3b with a manifold channel 5 disposed under the opening 3b. Each opening 3b is provided with a filter (not illustrated) for catching dust and dirt contained in ink. The front end portion of each manifold channel 5 branches into two sub-manifold channels 5a. Below a single one of the actuator unit 21, two sub-manifold channels 5a extend from each of the two openings 3b on both sides of the actuator unit 21 in the longitudinal direction of the ink-jet head 1. That is, below the single actuator unit 21, four sub-manifold channels 5a in total extend along the longitudinal direction of the ink-jet head 1. Each sub-manifold channel 5a is filled up with ink supplied from the ink reservoir 3.

[0038] FIG. 6 is an enlarged view of the region enclosed with an alternate long and short dash line in FIG. 5. Referring to FIGS. 5 and 6, on the upper face of each actuator unit 21, individual electrodes 35a each having a nearly rhombic shape in a plan view are regularly arranged in a matrix. In addition, individual electrodes 35b having the same shape as the individual electrodes 35a are disposed in the actuator unit 21 to vertically overlap the respective individual electrodes 35a. A large number of ink ejection ports 8 are regularly arranged in a matrix in the surface of the ink ejection region corresponding to the actuator unit 21 of the passage unit 4. In the passage unit 4, pressure chambers (cavities) 10 each having a nearly rhombic shape in a plan view somewhat larger than that of the individual electrodes 35a and 35b are regularly arranged in a matrix. Besides in the passage unit 4, apertures 12 are also regularly arranged in a matrix. These pressure chambers 10 and apertures 12 communicate with the corresponding ink ejection ports 8. The pressure chambers 10 are provided at positions corresponding to the respective individual electrodes 35a and 35b. In a plan view, the large part of the individual electrode 35a and 35b is included in a region of the corresponding pressure chamber 10. In FIGS. 5 and 6, for making it easy to understand the drawings, the pressure chambers 10, the apertures 12, etc., are illustrated with solid lines though they should be illustrated with broken lines because they are within the actuator unit 21 or the passage unit 4.

[0039] FIG. 7 is a partial sectional view of the head main body 1a of FIG. 4 along the longitudinal direction of a pressure chamber. As apparent from FIG. 7, each ink ejection port 8 is formed at the front end of a tapered nozzle. Each ink ejection port 8 communicates with a sub-manifold channel 5a through a pressure chamber 10 (length: 900 μm, width: 350 μm) and an aperture 12. Thus, within the ink-jet head 1 formed are ink passages 32 each extending from an ink tank to an ink ejection port 8 through an ink reservoir 3, a manifold channel 5, a sub-manifold channel 5a, an aperture 12, and a pressure chamber 10.

[0040] Referring to FIG. 7, the pressure chamber 10 and the aperture 12 are provided at different levels. Therefore, in the portion of the passage unit 4 corresponding to the ink ejection region under an actuator unit 21, an aperture 12 communicating with one pressure chamber 10 can be disposed within the same portion in plan view as a pressure chamber 10 neighboring the pressure chamber 10 communicating with the aperture 12. As a result, since pressure chambers 10 can be arranged close to each other at a high density, image printing at a high resolution can be realized with an ink-jet head 1 having a relatively small occupation area.

[0041] In the plane of FIGS. 5 and 6, pressure chambers 10 are arranged within an ink ejection region in two directions, i.e., a direction along the longitudinal direction of the ink-jet head 1 (first arrangement direction) and a direction somewhat inclining from the lateral direction of the ink-jet head 1 (second arrangement direction). The first and second arrangement directions form an angle somewhat smaller than the right angle. The ink ejection ports 8 are arranged at 50 dpi (dots per inch) in the first arrangement direction. On the other hand, the pressure chambers 10 are arranged in the second arrangement direction such that the ink ejection region corresponding to one actuator unit 21 include twelve pressure chambers 10. Therefore, within the whole width of the ink-jet head 1, in a region of the interval between two ink ejection ports 8 neighboring each other in the first arrangement direction, there are twelve ink ejection ports 8. At both ends of each ink ejection region in the first arrangement direction (corresponding to an oblique side of the actuator unit 21), the above condition is satisfied by making a compensation relation to the ink ejection region corresponding to the opposite actuator unit 21 in the lateral direction of the ink-jet head 1. Therefore, in the ink-jet head 1, by ejecting ink droplets in order through a large number of ink ejection ports 8 arranged in the first and second directions with relative movement of a paper along the lateral direction of the ink-jet head 1, printing at 600 dpi in the main scanning direction can be performed.

[0042] Next, the construction of the passage unit 4 will be described in more detail with reference to FIG. 8. FIG. 8 is a schematic view showing the positional relation among each pressure chamber 10, each ink ejection port 8, and each aperture (restricted passage) 12. Re-

ferring to FIG. 8, pressure chambers 10 are arranged in lines in the first arrangement direction at predetermined intervals at 500 dpi. Twelve lines of pressure chambers 10 are arranged in the second arrangement direction. As the whole, the pressure chambers 10 are two-dimensionally arranged in the ink ejection region corresponding to one actuator unit 21.

[0043] The pressure chambers 10 are classified into two kinds, i.e., pressure chambers 10a in each of which a nozzle is connected with the upper acute portion in FIG. 8, and pressure chambers 10b in each of which a nozzle is connected with the lower acute portion. Pressure chambers 10a and 10b are arranged in the first arrangement direction to form pressure chamber lines 11a and 11b, respectively. Referring to FIG. 8, in the ink ejection region corresponding to one actuator unit 21, from the lower side of FIG. 8, there are disposed two pressure chamber lines 11a and two pressure chamber lines 11b neighboring the upper side of the pressure chamber lines 11a. The four pressure chamber lines of the two pressure chamber lines 11a and the two pressure chamber lines 11b constitute a set of pressure chamber lines. Such a set of pressure chamber lines is repeatedly disposed three times from the lower side in the ink ejection region corresponding to one actuator unit 21. A straight line extending through the upper acute portion of each pressure chamber in each pressure chamber line 11a and 11b crosses the lower oblique side of each pressure chamber in the pressure chamber line neighboring the upper side of that pressure chamber line.

[0044] As described above, when viewing perpendicularly to FIG. 8, two first pressure chamber lines 11a and two pressure chamber lines 11b, in which nozzles connected with pressure chambers 10 are disposed at different positions, are arranged alternately to neighbor each other. Consequently, as the whole, the pressure chambers 10 are arranged regularly. On the other hand, nozzles are arranged in a concentrated manner in a central region of each set of pressure chamber lines constituted by the above four pressure chamber lines. Therefore, in case that each four pressure chamber lines constitute a set of pressure chamber lines and such a set of pressure chamber lines is repeatedly disposed three times from the lower side as described above, there is formed a region where no nozzle exists, in the vicinity of the boundary between each neighboring sets of pressure chamber lines, i.e., on both sides of each set of pressure chamber lines constituted by four pressure chamber lines. Wide sub-manifold channels 5a extend there for supplying ink to the corresponding pressure chambers 10. In this ink-jet head, in the ink ejection region corresponding to one actuator unit 21, four wide sub-manifold channels 5a in total are arranged in the first arrangement direction, i.e., one on the lower side of FIG. 8, one between the lowermost set of pressure chamber lines and the second lowermost set of pressure chamber lines, and two on both sides of the uppermost set of pressure chamber lines.

[0045] Referring to FIG. 8, nozzles communicating with ink ejection ports 8 for ejecting ink are arranged in the first arrangement direction at regular intervals at 50 dpi to correspond to the respective pressure chambers 10 regularly arranged in the first arrangement direction. On the other hand, while twelve pressure chambers 10 are regularly arranged also in the second arrangement direction forming an angle with the first arrangement direction, twelve nozzles corresponding to the twelve pressure chambers 10 include ones each communicating with the upper acute portion of the corresponding pressure chamber 10 and ones each communicating with the lower acute portion of the corresponding pressure chamber 10, as a result, they are not regularly arranged in the second arrangement direction at regular intervals.

[0046] If all nozzles communicate with the same-side acute portions of the respective pressure chambers 10, the nozzles are regularly arranged also in the second arrangement direction at regular intervals. In this case, nozzles are arranged so as to shift in the first arrangement direction by a distance corresponding to 600 dpi as resolution upon printing per pressure chamber line from the lower side to the upper side of FIG. 8. Contrastively in this ink-jet head, since four pressure chamber lines of two pressure chamber lines 11a and two pressure chamber lines 11b constitute a set of pressure chamber lines and such a set of pressure chamber lines is repeatedly disposed three times from the lower side, the shift of nozzle position in the first arrangement direction per pressure chamber line from the lower side to the upper side of FIG. 8 is not always the same.

[0047] In the ink-jet head 1, a band region R will be discussed that has a width (about 508.0 μ m) corresponding to 50 dpi in the first arrangement direction and extends perpendicularly to the first arrangement direction. In this band region R, any of twelve pressure chamber lines includes only one nozzle. That is, when such a band region R is defined at an optional position in the ink ejection region corresponding to one actuator unit 21, twelve nozzles are always distributed in the band region R. The positions of points respectively obtained by projecting the twelve nozzles onto a straight line extending in the first arrangement direction are distant from each other by a distance corresponding to 600 dpi as resolution upon printing.

[0048] When the twelve nozzles included in one band region R are denoted by (1) to (12) in order from one whose projected image onto a straight line extending in the first arrangement direction is the leftmost, the twelve nozzles are arranged in the order of (1), (7), (2), (8), (5), (11), (6), (12), (9), (3), (10), and (4) from the lower side.

[0049] In the thus-constructed ink-jet head 1, by properly driving active layers in the actuator unit 21, a character, an figure, or the like, having a resolution of 600 dpi can be formed. That is, by selectively driving active layers corresponding to the twelve pressure chamber lines in order in accordance with the transfer of a print

medium, a specific character or figure can be printed on the print medium.

[0050] By way of example, a case will be described wherein a straight line extending in the first arrangement direction is printed at a resolution of 600 dpi. First, a case will be briefly described wherein nozzles communicate with the same-side acute portions of pressure chambers 10. In this case, in accordance with transfer of a print medium, ink ejection starts from a nozzle in the lowermost pressure chamber line in FIG. 8. Ink ejection is then shifted upward with selecting a nozzle belonging to the upper neighboring pressure chamber line in order. Ink dots are thereby formed in order in the first arrangement direction with neighboring each other at 600 dpi. Finally, all the ink dots form a straight line extending in the first arrangement direction at a resolution of 600 dpi.

[0051] On the other hand, in this ink-jet head, ink ejection starts from a nozzle in the lowermost pressure chamber line 11a in FIG. 8, and ink ejection is then shifted upward with selecting a nozzle communicating with the upper neighboring pressure chamber line in order in accordance with transfer of a print medium. In this embodiment, however, since the positional shift of nozzles in the first arrangement direction per pressure chamber line from the lower side to the upper side is not always the same, ink dots formed in order in the first arrangement direction in accordance with the transfer of the print medium are not arranged at regular intervals at 600 dpi.

[0052] More specifically, as shown in FIG. 8, in accordance with the transfer of the print medium, ink is first ejected through a nozzle (1) communicating with the lowermost pressure chamber line 11a in FIG. 8 to form a dot row on the print medium at intervals corresponding to 50 dpi (about 508.0 μ m). After this, as the print medium is transferred and the straight line formation position has reached the position of a nozzle (7) communicating with the second lowermost pressure chamber line 11a, ink is ejected through the nozzle (7). The second ink dot is thereby formed at a position shifted from the first formed dot position in the first arrangement direction by a distance of six times the interval corresponding to 600 dpi (about 42.3 μ m) (about 42.3 μ m $\times$ 6 = about 254.0 μ m).

[0053] Next, as the print medium is further transferred and the straight line formation position has reached the position of a nozzle (2) communicating with the third lowermost pressure chamber line 11b, ink is ejected through the nozzle (2). The third ink dot is thereby formed at a position shifted from the first formed dot position in the first arrangement direction by a distance of the interval corresponding to 600 dpi (about 42.3 μ m). As the print medium is further transferred and the straight line formation position has reached the position of a nozzle (8) communicating with the fourth lowermost pressure chamber line 11b, ink is ejected through the nozzle (8). The fourth ink dot is thereby formed at a position shifted from the first formed dot position in the first arrangement direction by a distance of seven times the

interval corresponding to 600 dpi (about 42.3 μ m) (about 42.3 μ m $\times$ 7 = about 296.3 μ m). As the print medium is further transferred and the straight line formation position has reached the position of a nozzle (5) communicating with the fifth lowermost pressure chamber line 11a, ink is ejected through the nozzle (5). The fifth ink dot is thereby formed at a position shifted from the first formed dot position in the first arrangement direction by a distance of four times the interval corresponding to 600 dpi (about 42.3 μ m) (about 42.3 μ m $\times$ 4 = about 169.3 μ m).

[0054] After this, in the same manner, ink dots are formed with selecting nozzles communicating with pressure chambers 10 in order from the lower side to the upper side in FIG. 8. In this case, when the number of a nozzle in FIG. 8 is N, an ink dot is formed at a position shifted from the first formed dot position in the first arrangement direction by a distance corresponding to (magnification $n = N - 1$) (interval corresponding to 600 dpi). When the twelve nozzles have been finally selected, the gap between the ink dots to be formed by the nozzles (1) in the lowermost pressure chamber lines 11a in FIG. 8 at an interval corresponding to 50 dpi (about 508.0 μ m) is filled up with eleven dots formed at intervals corresponding to 600 dpi (about 42.3 μ m). Therefore, as the whole, a straight line extending in the first arrangement direction can be drawn at a resolution of 600 dpi.

[0055] Next, the sectional construction of the ink-jet head 1 will be described. FIG. 9 is a partial exploded view of the head main body 1a of FIG. 4. FIG. 10 is an enlarged sectional view when laterally viewing the region enclosed with an alternate long and short dash line in FIG. 7. Referring to FIGS. 7 and 9, a principal portion on the bottom side of the ink-jet head 1 has a layered structure laminated with ten sheet materials in total, i. e., from the top, an actuator unit 21, a cavity plate 22, a base plate 23, an aperture plate 24, a supply plate 25, manifold plates 26, 27, and 28, a cover plate 29, and a nozzle plate 30. Of them, nine plates other than the actuator unit 21 constitute a passage unit 4.

[0056] As described later in detail, the actuator unit 21 is laminated with five piezoelectric sheets 41 to 45 (see FIG. 10) and provided with electrodes so that only the uppermost layer and the second layer neighboring the uppermost layer include portions to be active when an electric field is applied (hereinafter, simply referred to as "layer including active layers (active portions)") and the remaining three layers are inactive. The cavity plate 22 is made of metal, in which a large number of substantially rhombic openings are formed corresponding to the respective pressure chambers 10. The base plate 23 is made of metal, in which a communication hole between each pressure chamber 10 of the cavity plate 22 and the corresponding aperture 12, and a communication hole between the pressure chamber 10 and the corresponding ink ejection port 8 are formed. The aperture plate 24 is made of metal, in which, in addition to apertures 12, communication holes are formed for connecting each pressure chamber 10 of the cavity

plate 22 with the corresponding ink ejection port 8. The supply plate 25 is made of metal, in which communication holes between each aperture 12 and the corresponding sub-manifold channel 5a and communication holes for connecting each pressure chamber 10 of the cavity plate 22 with the corresponding ink ejection port 8 are formed. Each of the manifold plates 26, 27, and 28 is made of metal, which defines an upper portion of each sub-manifold channel 5a and in which communication holes are formed for connecting each pressure chamber 10 of the cavity plate 22 with the corresponding ink ejection port 8. The cover plate 29 is made of metal, in which communication holes are formed for connecting each pressure chamber 10 of the cavity plate 22 with the corresponding ink ejection port 8. The nozzle plate 30 is made of metal, in which tapered ink ejection ports 8 each functioning as a nozzle are formed for the respective pressure chambers 10 of the cavity plate 22.

[0057] These ten sheets 21 to 30 are put in layers with being positioned to each other to form such an ink passage 32 as illustrated in FIG. 7. The ink passage 32 first extends upward from the sub-manifold channel 5a, then extends horizontally in the aperture 12, then further extends upward, then again extends horizontally in the pressure chamber 10, then extends obliquely downward in a certain length to get apart from the aperture 12, and then extends vertically downward toward the ink ejection port 8.

[0058] Referring to FIG. 10, the actuator unit 21 includes five piezoelectric sheets 41, 42, 43, 44, and 45 having the same thickness of about 15 μ m. These piezoelectric sheets 41 to 45 are made into a continuous layered flat plate (continuous flat layers) that is so disposed as to extend over many pressure chambers 10 formed within one ink ejection region in the ink-jet head 1. Since the piezoelectric sheets 41 to 45 are disposed so as to extend over many pressure chambers 10 as the continuous flat layers, the individual electrodes 35a and 35b can be arranged at a high density by using, e.g., a screen printing technique. Therefore, also the pressure chambers 10 formed at positions corresponding to the individual electrodes 35a and 35b can be arranged at a high density. This makes it possible to print a high-resolution image. In this embodiment, each of the piezoelectric sheets 41 to 45 is made of a lead zirconate titanate (PZT)-base ceramic material having ferroelectricity.

[0059] Between the uppermost piezoelectric sheet 41 and the piezoelectric sheet 42 neighboring downward the piezoelectric sheet 41, an about 2 μ m-thick common electrode 34a is interposed formed on the whole of the lower and upper faces of the piezoelectric sheets. Also, between the piezoelectric sheet 43 neighboring downward the piezoelectric sheet 42 and the piezoelectric sheet 44 neighboring downward the piezoelectric sheet 43, an about 2 μ m-thick common electrode 34b is interposed formed like the common electrode 34a. On the upper face of the piezoelectric sheet 41, an about 1 μ m-thick individual electrode 35a is formed to correspond

to each pressure chamber 10 (see FIG. 6). The individual electrode 35a has a similar shape (length: 850 μ m, width: 250 μ m) to that of the pressure chamber 10 in a plan view, so that a projection image of the individual electrode 35a projected along the thickness direction of the individual electrode 35a is included in the corresponding pressure chamber 10. Further, between the piezoelectric sheets 42 and 43, an about 2 μ m-thick individual electrode 35b is interposed formed like the individual electrode 35a. No electrode is provided between the piezoelectric sheet 44 neighboring downward the piezoelectric sheet 43 and the piezoelectric sheet 45 neighboring downward the piezoelectric sheet 44, and on the lower face of the piezoelectric sheet 45. Each of the electrodes 34a, 34b, 35a, and 35b is made of, e.g., an Ag-Pd-base metallic material.

[0060] The common electrodes 34a and 34b are grounded in a not-illustrated region. Thus, the common electrodes 34a and 34b are kept at the ground potential at a region corresponding to any pressure chamber 10. The individual electrodes 35a and 35b in each pair corresponding to a pressure chamber 10 are in contact with leads (not illustrated) wired within the FPC 136 independently of another pair of individual electrodes so that the potential of each pair of individual electrodes can be controlled independently of that of another pair. The individual electrodes 35a and 35b are connected to the driver IC 132 through the leads. In this case, the individual electrodes 35a and 35b in each pair vertically arranged may be connected to the driver IC 132 through the same lead. In a modification, many pairs of common electrodes 34a and 34b each having a shape larger than that of a pressure chamber 10 so that the projection image of each common electrode projected along the thickness direction of the common electrode may include the pressure chamber, may be provided for each pressure chamber 10. In another modification, many pairs of common electrodes 34a and 34b each having a shape somewhat smaller than that of a pressure chamber 10 so that the projection image of each common electrode projected along the thickness direction of the common electrode may be included in the pressure chamber, may be provided for each pressure chamber 10. Thus, the common electrode 34a or 34b may not always be a single conductive sheet formed on the whole of the face of a piezoelectric sheet. In the above modifications, however, all the common electrodes must be electrically connected with one another so that the portion corresponding to any pressure chamber 10 may be at the same potential.

[0061] In the ink-jet head 1, the piezoelectric sheets 41 to 45 are polarized in their thickness direction. That is, the actuator unit 21 has a so-called unimorph structure in which the upper (i.e., distant from the pressure chamber 10) three piezoelectric sheets 41 to 43 are layers wherein active layers are present, and the lower (i.e., near the pressure chamber 10) two piezoelectric sheets 44 and 45 are made into inactive layers. There-

fore, when the individual electrodes 35a and 35b in a pair are set at a positive or negative predetermined potential, if the polarization is in the same direction as the electric field for example, the electric field-applied portion in the piezoelectric sheets 41 to 43 sandwiched by the common and individual electrodes works as an active layer (pressure generation portion) and contracts perpendicularly to the polarization by the transversal piezoelectric effect. On the other hand, since the piezoelectric sheets 44 and 45 are influenced by no electric field, they do not contract in themselves. Thus, a difference in strain perpendicular to the polarization is produced between the upper piezoelectric sheets 41 to 43 and the lower piezoelectric sheets 44 and 45. As a result, the whole of the piezoelectric sheets 41 to 45 is ready to deform into a convex shape toward the inactive side (unimorph deformation). At this time, as illustrated in FIG. 10, the lowermost face of the piezoelectric sheets 41 to 45 is fixed to the upper face of the partition (the cavity plate) 22 partitioning pressure chambers, as a result, the piezoelectric sheets 41 to 45 deform into a convex shape toward the pressure chamber side. Therefore, the volume of the pressure chamber 10 is decreased to raise the pressure of ink. The ink is thereby ejected through the ink ejection port 8. After this, when the individual electrodes 35a and 35b are returned to the same potential as that of the common electrodes 34a and 34b, the piezoelectric sheets 41 to 45 return to the original shape and the pressure chamber 10 also returns to its original volume. Thus, the pressure chamber 10 sucks ink therein through the manifold channel 5.

[0062] In another driving method, all the individual electrodes 35a and 35b are set in advance at a different potential from that of the common electrodes 34a and 34b. When an ejecting request is issued, the corresponding pair of individual electrodes 35a and 35b is once set at the same potential as that of the common electrodes 34a and 34b. After this, at a predetermined timing, the pair of individual electrodes 35a and 35b is again set at the different potential from that of the common electrodes 34a and 34b. In this case, at the timing when the pair of individual electrodes 35a and 35b is set at the same potential as that of the common electrodes 34a and 34b, the piezoelectric sheets 41 to 45 return to their original shapes. The corresponding pressure chamber 10 is thereby increased in volume from its initial state (the state that the potentials of both electrodes differ from each other), to suck ink from the manifold channel 5 into the pressure chamber 10. After this, at the timing when the pair of individual electrodes 35a and 35b is again set at the different potential from that of the common electrodes 34a and 34b, the piezoelectric sheets 41 to 45 deform into a convex shape toward the pressure chamber 10. The volume of the pressure chamber 10 is thereby decreased and the pressure of ink in the pressure chamber 10 increases to eject ink.

[0063] On the other hand, in case that the polarization occurs in the reverse direction to the electric field ap-

plied to the piezoelectric sheets 41 to 43, the active layers in the piezoelectric sheets 41 and 42 sandwiched by the individual electrodes 35a and 35b and the common electrodes 34a and 34b are ready to elongate perpendicularly to the polarization by the transversal piezoelectric effect. As a result, the piezoelectric sheets 41 to 45 deform into a concave shape toward the pressure chamber 10. Therefore, the volume of the pressure chamber 10 is increased to suck ink from the manifold channel 5. After this, when the individual electrodes 35a and 35b return to their original potential, the piezoelectric sheets 41 to 45 also return to their original flat shape. The pressure chamber 10 thereby returns to its original volume to eject ink through the ink ejection port 8.

[0064] Next, a manufacturing method of the ink-jet head 1 will be described.

[0065] To manufacture the ink-jet head 1, a passage unit 4 and each actuator unit 21 are separately manufactured in parallel and then both are bonded to each other. To manufacture the passage unit 4, each plate 22 to 30 to constitute the passage unit 4 is subjected to etching using a patterned photoresist as a mask, thereby forming openings as illustrated in FIGS. 7 and 9 in the respective plates 22 to 30. After this, the nine plates 22 to 30 are put in layers with adhesives being interposed so as to form therein ink passages 32. The nine plates 22 to 30 are thereby bonded to each other to form a passage unit 4.

[0066] To manufacture each actuator unit 21, first, a conductive paste to be individual electrodes 35b is printed in a pattern on a ceramic green sheet to be a piezoelectric sheet 43. In parallel with this, conductive pastes to be common electrodes 34a and 34b are printed in a pattern on ceramic green sheets to be piezoelectric sheets 42 and 44. After this, five green sheets to be piezoelectric sheets 41 to 45 are put in layers with being positioned with a jig. The thus obtained layered structure is then baked at a predetermined temperature. After this, individual electrodes 35a are formed on the piezoelectric sheet 41 of the baked layered structure. For example, the individual electrodes 35a may be formed in the manner that a conductive film is plated on the whole of one surface of the piezoelectric sheet 41 and then unnecessary portions of the conductive film are removed by laser patterning. Alternatively, the individual electrodes 35a may be formed by depositing a conductive film on the piezoelectric sheet 41 by PVD (Physical Vapor Deposition) using a mask having openings at portions corresponding to the respective individual electrodes 35a. To this process, the manufacture of the actuator unit 21 is completed.

[0067] Next, the actuator unit 21 manufactured as described above is bonded to the passage unit 4 with an adhesive so that the piezoelectric sheet 45 may be in contact with the cavity plate 22. At this time, both are bonded to each other on the basis of marks for positioning formed on the surface of the cavity plate 22 of the passage unit 4 and the surface of the piezoelectric sheet

41, respectively.

[0068] After this, through-holes are formed for connecting vertically arranged corresponding individual electrodes 35a and 35b with each other. The through-holes are then filled up with a conductive material. After this, for supplying electric signals to the individual electrodes 35a and 35b and the common electrodes 34a and 34b, the FPC 136 is bonded onto and electrically connected with bonding positions corresponding to the respective electrodes on the actuator unit 21 by soldering. Further, through a predetermined process, the manufacture of the ink-jet head 1 is completed.

[0069] As described above, differently from the other electrodes, the only individual electrodes 35a are not baked together with the ceramic materials to be the piezoelectric sheets 41 to 45. The reason is as follows. That is, since the individual electrodes 35a are exposed, they are apt to evaporate at a high temperature upon baking. As a result, it is difficult to control the thickness of them in comparison with the other electrodes 34a, 34b, and 35b being covered with ceramic materials. However, even the thickness of the other electrodes 34a, 34b, and 35b may somewhat decrease upon baking. Therefore, it is difficult to form them into a small thickness if keeping the continuity after baking is taken into consideration. Contrastively, since the individual electrodes 35a are formed by the above-described technique after baking, they can be formed into a smaller thickness than the other electrodes 34a, 34b, and 35b. Thus, in the ink-jet head 1, by forming the individual electrodes 35a in the uppermost layer into a smaller thickness than the other electrodes 34a, 34b, and 35b, the deformation of the piezoelectric sheets 41 to 43 including active layers is hard to be restricted by the individual electrodes 35a. Efficiencies (electrical efficiency and area efficiency) of the actuator unit 21 are improved thereby.

[0070] In the ink-jet head 1, since the piezoelectric sheets 41 to 43 including active layers and the piezoelectric sheets 44 and 45 as the inactive layers are made of the same material, the material need not be changed in the manufacturing process. Thus, they can be manufactured through a relatively simple process, and a reduction of manufacturing cost is expected. Besides, for the reason that each of the piezoelectric sheets 41 to 43 including active layers and the piezoelectric sheets 44 and 45 as the inactive layers has substantially the same thickness, a further reduction of cost can be intended by simplifying the manufacturing process. This is because the thickness control can easily be performed when the ceramic materials to be the piezoelectric sheets are applied to be put in layers.

[0071] Besides, in the ink-jet head 1, separate actuator units 21 corresponding to the respective ink ejection regions are bonded onto the passage unit 4 to be arranged along the longitudinal direction of the passage unit 4. Therefore, each of the actuator units 21 apt to be uneven in dimensional accuracy and in positional accu-

racy of the individual electrodes 35a and 35b because they are formed by sintering or the like, can be positioned to the passage unit 4 independently from another actuator unit 21. Thus, even in case of a long head, the increase in shift of each actuator unit 21 from the accurate position on the passage unit 4 is restricted, and both can accurately be positioned to each other. Therefore, as to even an individual electrodes 35a and 35b relatively apart from a mark, the individual electrodes 35a and 35b can not considerably be shifted from the predetermined position to the corresponding pressure chamber 10. As a result, good ink ejection performance can be obtained and the manufacture yield of the ink-jet heads 1 is remarkably improved. On the other hand, differently from the above, if a long-shaped actuator unit 21 is made like the passage unit 4, the more the individual electrodes 35a and 35b are apart from the mark, the larger the shift of the individual electrodes 35a and 35b is from the predetermined position on the corresponding pressure chamber 10 in a plan view when the actuator unit 21 is laid over the passage unit 4. As a result, the ink ejection performance of a pressure chamber 10 relatively apart from the mark is deteriorated and thus the uniformity of the ink ejection performance in the ink-jet head 1 is not obtained.

[0072] In addition, in the ink-jet head 1 constructed as described above, by sandwiching the piezoelectric sheets 41 to 43 by the common electrodes 34a and 34b and the individual electrodes 35a and 35b, the volume of each pressure chamber 10 can easily be changed by the piezoelectric effect. Further, since each of the piezoelectric sheets 41 to 43 including active layers is in a shape of a continuous flat layer, it can easily be manufactured.

[0073] Besides, the ink-jet head 1 has the actuator units 21 each having a unimorph structure in which the piezoelectric sheets 44 and 45 near each pressure chamber 10 are inactive and the piezoelectric sheet 41 to 43 distant from each pressure chamber 10 include active layers. Therefore, the change in volume of each pressure chamber 10 can be increased by the transversal piezoelectric effect. As a result, in comparison with an ink-jet head in which a layer including active layers is provided on the pressure chamber 10 side and a inactive layer is provided on the opposite side, lowering the voltage to be applied to the individual electrodes 35a and 35b and/or high integration of the pressure chambers 10 can be intended. By lowering the voltage to be applied, the driver for driving the individual electrodes 35a and 35b can be made small in size and the cost can be held down. In addition, each pressure chamber 10 can be made small in size. Besides, even in case of a high integration of the pressure chambers 10, a sufficient amount of ink can be ejected. Thus, a decrease in size of the head 1 and a highly dense arrangement of printing dots can be realized.

[0074] Further, in the ink-jet head 1, each actuator unit 21 has a substantially trapezoidal shape. The actuator

units 21 are arranged in two lines in a zigzag manner so that the parallel opposed sides of each actuator unit 21 extend along the longitudinal direction of the passage unit 4, and the oblique sides of each neighboring actuator units 21 overlap each other in the lateral direction of the passage unit 4. Since the oblique sides of each neighboring actuator units 21 thus overlap each other, when the ink-jet head 1 moves along the lateral direction of the ink-jet head 1 relatively to a print medium, the pressure chambers 10 existing along the lateral direction of the passage unit 4 can compensate each other. As a result, with realizing high-resolution printing, a small-size ink-jet head 1 having a very narrow width can be realized.

[0075] Besides, since many pressure chambers 10 neighboring each other are arranged in a matrix in the passage unit 4, the many pressure chambers 10 can be disposed within a relatively small size at a high density.

[0076] In the above-described ink-jet head 1, trapezoidal actuator units are arranged in two lines in a zigzag manner. But, each actuator unit may not be trapezoidal. Besides, actuator units may be arranged in only one line along the longitudinal direction of the passage unit. Actuator units may be arranged in three or more lines in a zigzag manner.

[0077] Next, a second embodiment of the present invention will be described. FIG. 11 is a plan view of a head main body of an ink-jet head according to this embodiment. In the ink-jet head and ink-jet printer according to this embodiment, since the parts other than the head main body is similar to that of the above-described first embodiment, the detailed description thereof is omitted here.

[0078] Referring to FIG. 11, a head main body 201 of an ink-jet head according to this embodiment has a rectangular shape in a plan view extending in one direction (main scanning direction). The head main body 201 includes a passage unit 204 in which a large number of pressure chambers 210 and a large number of ink ejection ports 208 are formed as will be described later. Onto the upper face of the passage unit 204, two parallelogrammic actuator units 221 (In FIG. 11, the right and left ones are denoted by reference numerals 221a and 221b, respectively) are bonded to neighbor each other. Each actuator unit 221 is disposed so that its one side B extends along the longitudinal direction of the head main body 201. The neighboring actuator units 221 are so disposed as to be aligned with each other along the width (shorter length) direction of the head main body 201 with their oblique sides C being close to each other. An ink supply port 202 is open in the upper face of the passage unit 204. The ink supply port 202 is connected with an ink supply source through a not-illustrated passage.

[0079] Referring to FIG. 12 that is a view of the head main body 201 at the reverse angle to FIG. 11 (a view from the printing face side), two parallelogrammic ink ejection regions R1 are provided in the lower face of the

passage unit 204 to correspond to the respective regions where the actuator units 221 are disposed. A large number of small-diameter ink ejection ports 208 are arranged in the surface of each ink ejection region R1.

[0080] This embodiment shows a case of monochrome printing. Thus, the ink supply port 202 is supplied with ink of a single color (e.g., black). For performing multicolor printing, head main bodies 201 corresponding in number to colors (for example, in case of four colors of yellow, cyan, magenta, and black, four head main bodies 201) are aligned along the lateral direction of the passage unit. The head main bodies 201 are supplied with color inks different from one another to print.

[0081] FIG. 13 is a sectional view illustrating the internal construction of the passage unit 204. Referring to FIG. 13, a manifold channel 205 is formed in the passage unit 204. The manifold channel 205 communicates with an ink supply source through the ink supply port 202, as a result, the manifold channel 205 is always filled up with ink. The ink supply port 202 is preferably provided with a filter for catching dust and dirt contained in ink.

[0082] The manifold channel 205 is formed in the most part of passage unit 204 to extend over the two ink ejection regions R1. In part of the manifold channel 205 corresponding to each ink ejection region R1, a large number of slender parallelogrammic island portions 205a are formed to be arranged at regular intervals. The length of each island portion 205a is along the longitudinal direction of the passage unit 204. In this construction, ink supplied through the ink supply port 202 passes between each neighboring island portions 205a in the manifold channel 205, and then it is distributed to pressure chambers 210 as described later formed in the passage unit 204 in each ink ejection region R1.

[0083] Referring to FIG. 15, each ink ejection port 208 is made into a tapered nozzle. The ink ejection port 208 communicates with a manifold channel 205 through a pressure chamber 210 having a substantially parallelogrammic shape in a plan view and an aperture 212. In this construction, ink is supplied from the manifold channel 205 to the pressure chamber 210 through the aperture 212. By driving an actuator unit 221 as will be described later, jet energy is applied to ink in the pressure chamber 210 to jet ink through the ink ejection port 208.

[0084] FIG. 14 illustrates a detailed construction of the region denoted by reference Q in FIG. 13. As apparent from FIG. 14, in a region of the upper face of the passage unit 204 corresponding to an ink ejection region R1, a large number of pressure chambers 210 are arranged in a matrix to neighbor each other. Since the pressure chambers 210 are formed at a different level from that of the apertures 212 as illustrated in FIG. 15, such an arrangement as illustrated in FIG. 14 is possible in which each aperture 212 connected with a pressure chamber 210 overlaps another pressure chamber 210. As a result, a highly dense arrangement of the pressure chambers 210 can be realized and this may contribute a de-

crease in size of the head main body 201 and an increase in resolution of an image to be formed.

[0085] FIG. 15 illustrates a specific construction of a passage from a manifold channel 205 to an ink ejection port 208. Referring to FIG. 15, the passage unit 204 is laminated with nine sheet materials in total, i.e., a cavity plate 222, a base plate 223, an aperture plate 224, a supply plate 225, manifold plates 226, 227, and 228, a cover plate 229, and a nozzle plate 230. The above-described actuator units 221 are bonded to the upper face of the passage unit 204 to constitute a head main body 201. The detailed construction of each actuator unit 221 will be described later.

[0086] A parallelogrammic opening is formed in the cavity plate 222 to form a pressure chamber 210 as described above. A tapered ink ejection port 208 is formed in the nozzle plate 230 with a press. Communication holes 251 are formed through each of the plates 223 to 229 between the plates 222 and 230. The pressure chamber 210 communicates with the ink ejection port 208 through the communication holes 251. An aperture 212 as an elongated hole is formed in the aperture plate 224. One end of the aperture 212 is connected with an end portion of the pressure chamber 210 (opposite to the end portion connecting with the ink ejection port 208) through a communication hole 252 formed in the base plate 223. The aperture 212 is for properly controlling the amount of ink to be supplied to the pressure chamber 210 and preventing too much or too little ink from being jetted through the ink ejection port 208. A communication hole 253 is formed in the supply plate 225. The communication hole 253 connects the other end of the aperture 212 with the manifold channel 205.

[0087] Each of the nine plates 222 to 230 constituting the passage unit 204 is made of metal. The pressure chamber 210, the aperture 212, and the communication holes 251, 252, and 253 are formed by selectively etching each metallic plate using a mask pattern. The nine plates 222 to 230 are put in layers and bonded to each other with being positioned to each other so that the passage as illustrated in FIG. 15 is formed therein.

[0088] Referring to FIG. 16, each actuator unit 221 includes five piezoelectric sheets 241 to 245 having the same thickness of about 15 μ m. These piezoelectric sheets 241 to 245 are made into continuous flat layers. One actuator unit 221 is disposed to extend over many pressure chambers 210 formed in one ink ejection region R1 of the head main body 201. This can realize a highly dense arrangement of individual electrodes 235a and 235b in the actuator unit 221. Each of the piezoelectric sheets 241 to 245 is made of a lead zirconate titanate (PZT)-base ceramic material having ferroelectricity.

[0089] Between the first and second piezoelectric sheets 241 and 242 from the top, an about 2 μ m-thick common electrode 234a is interposed formed on substantially the whole of the lower and upper faces of the piezoelectric sheets. Also, between the third and fourth

piezoelectric sheets 243 and 244, an about 2 m-thick common electrode 234b is interposed. On the upper face of the first piezoelectric sheet 241, an about 1 m-thick individual electrode 235a is formed to correspond to each pressure chamber 210. As illustrated in FIG. 13, the individual electrode 235a has a similar shape to that of the pressure chamber 210 in a plan view though the individual electrode 235a is somewhat smaller than the pressure chamber 210. The individual electrode 235a is disposed such that the center of the individual electrode 235a coincides with the center of the corresponding pressure chamber 210. Further, between the second and third piezoelectric sheets 242 and 243, an about 2 m-thick individual electrode 235b is interposed formed like the individual electrode 235a. The portion where the individual electrodes 235a and 235b are disposed corresponds to a pressure generation portion A for applying pressure to ink in the pressure chamber 210. No electrode is provided between the fourth and fifth piezoelectric sheets 244 and 245, and on the lower face of the fifth piezoelectric sheet 245. Each of the electrodes 234a, 234b, 235a, and 235b is made of, e.g., an Ag-Pd-base metallic material.

[0090] The common electrodes 234a and 234b are grounded in a not-illustrated region. Thus, the common electrodes 234a and 234b are kept at the ground potential at a region corresponding to any pressure chamber 210. In order that the individual electrodes 235a and 235b in each pair corresponding to a pressure chamber 210 can be controlled in potential independently of another pair, they are connected with a suitable driver IC through a lead provided separately for each pair of individual electrodes 235a and 235b.

[0091] In the head main body 201, the piezoelectric sheets 241 to 245 are to be polarized in their thickness. That is, the actuator unit 221 has a so-called unimorph structure in which the upper (i.e., distant from the pressure chamber 210) three piezoelectric sheets 241 to 243 are layers including active layers, and the lower (i.e., near the pressure chamber 210) two piezoelectric sheets 244 and 245 are made into inactive layers.

[0092] In this structure, when the individual electrodes 235a and 235b in a pair are set at a positive or negative predetermined potential, if the polarization is in the same direction as the electric field for example, the portion (an active layer, i.e., a pressure generation portion) in the piezoelectric sheets 241 to 243 sandwiched by the common and individual electrodes contracts perpendicularly to the polarization. On the other hand, since the inactive piezoelectric sheets 244 and 245 are influenced by no electric field, they do not contract in themselves. Thus, a difference in strain along the polarization is produced between the upper piezoelectric sheets 241 to 243 and the lower piezoelectric sheets 244 and 245. As a result, the whole of the piezoelectric sheets 241 to 245 is ready to deform into a convex shape toward the inactive side (unimorph deformation). At this time, since the lower face of the lowermost piezoelectric sheet 245

is fixed to the upper face of the partition partitioning pressure chambers 210, the pressure generation portion A of the piezoelectric sheets 241 to 245 deforms into a convex shape toward the pressure chamber 210 side to decrease the volume of the pressure chamber 210. As a result, the pressure of ink is raised and ink is thereby ejected through the ink ejection port 208. After this, when application of the driving voltage to the individual electrodes 235a and 235b is stopped, the piezoelectric sheets 241 to 245 return to the original shape and the pressure chamber 210 also returns to its original volume. Thus, the pressure chamber 210 sucks ink therein through the manifold channel 205.

[0093] Next, the shape of the two actuator units 221a and 221b and the arrangement of individual electrodes 235a and 235b (in other words, the arrangement of pressure generation portions A) will be described. FIG. 17 illustrates the shape of an actuator unit 221a and the arrangement of pressure generation portions. FIG. 18 shows the relation between a seam portion between the actuator units 221a and 221b and pressure generation portions in an additional region.

[0094] The head main body 201 includes two actuator units 221a and 221b as described above. The two actuator units 221a and 221b have quite the same shape and the same arrangement of pressure generation portions A.

[0095] As illustrated in FIGS. 11 and 17, the actuator unit 221a is parallelogrammic, which is disposed so that its one side B extends in parallel with the longitudinal direction of the passage unit 204 and its other side C inclines to the longitudinal direction of the passage unit 204. As illustrated in FIG. 17, in the actuator unit 221a, two regions P1 and P2 are provided that are separated in the lateral direction of the passage unit 204 by a straight line along the longitudinal direction of the passage unit 204. That is, the regions P1 and P2 neighbor each other in the lateral direction of the passage unit 204.

[0096] In the basic region P1 of the two regions P1 and P2, a large number of pressure generation portions A1 are arranged with neighboring each other in a matrix along the longitudinal direction of the passage unit 204 and along the other side C of the parallelogram.

[0097] In the other region (additional region P2) than the basic region P1, pressure generation portions A2 are arranged with neighboring each other in a matrix only in the vicinity of an acute corner D of the parallelogram near to the actuator unit 221b.

[0098] When the two actuator units 221a and 221b thus constructed are arranged in line along the longitudinal direction of the passage unit 204 as illustrated in FIG. 11, as illustrated in FIG. 18, the pressure generation portions A2 of the additional region P2 provided in the actuator unit 221a are in a place corresponding to a region (hatched region G in FIG. 18) where no pressure generation portion A can be disposed in the basic region P1 because it is in the seam between the actuator units

221a and 221b. That is, the pressure generation portions A2 of the additional region P2 are disposed to correspond to a gap portion G between the pressure generation portions A1 of the basic region P1 provided in the actuator unit 221a and the pressure generation portions A1 of the basic region P1 provided in the neighboring actuator unit 221b. Thus, although no separate actuator unit is provided for ejecting ink through the gap portion G, the head main body 201 can be provided that can perform printing with no break through the longitudinal direction of the passage unit.

[0099] In other words, since no pressure generation portion can be disposed in the region (region G) near the seam portion between the actuator units 221a and 221b, no pressure chamber 210 and no ink ejection port 208 also can be disposed in that region. Therefore, if the pressure generation portions A2 were not disposed in the additional region P2 provided in the actuator unit 221a, printing in the portion corresponding to the gap portion G cannot be done, as a result, a portion where ink ejection is impossible is produced in the seam portion between the actuator units 221a and 221b. But, since the pressure generation portions A2 are disposed in the additional region P2 provided in the actuator unit 221a in a portion overlapping that region G in the lateral direction of the passage unit, there is no portion where ink ejection is impossible. As a result, an image with no break can be formed on a paper.

[0100] As described above, in this embodiment, the actuator unit 221 includes lines in each of which a large number of pressure generation portions A1 and A2 are arranged along the longitudinal direction of the passage unit 204. As for the lengths of these lines along the longitudinal direction of the passage unit 204, each line in the basic region P1 is longer than each line in the additional region P2. Besides, as for the number of lines along the lateral direction of the passage unit 204, the number of lines in the additional region P2 is the same as the number of lines that might exist in the length of the corresponding region G along the lateral direction of the passage unit 204. Therefore, if an imaginary straight line is drawn to extend along the lateral direction of the passage unit 204, the number of lines that the imaginary straight line crosses in the region where the neighboring actuator units 221a and 221b overlap each other is the same as the number of lines that the imaginary straight line crosses in the region where the neighboring actuator units 221a and 221b do not overlap each other.

[0101] The above-described feature can be achieved only by arranging two actuator units 221a and 221b having the same construction. Thus, the arrangement of parts can be simplified and the cost and the number of process steps necessary for designing or manufacturing the actuator units 221a and 221b can be reduced.

[0102] The arrangement of pressure generation portions A in the actuator unit 221 described in this embodiment is by way of example. For instance, such an actuator unit 255 as illustrated in FIG. 19 may be used.

FIG. 19 illustrates another example of arrangement of pressure generation portions in an actuator unit. FIG. 20 shows the relation between a seam portion between actuator units and pressure generation portions in an additional region in the arrangement of FIG. 19.

[0103] The actuator unit 255a of FIG. 19 is divided into three regions P11, P12, and P13 in the lateral direction of the passage unit. The middle region P11 in the lateral direction of the passage unit is used as a basic region and the remaining regions P12 and P13 are used as additional regions.

[0104] Like the arrangement in FIG. 17, in the basic region P11, a large number of pressure generation portions A11 are arranged with neighboring each other in a matrix along the longitudinal direction of the passage unit and along the other side C of the parallelogram. In an additional region P12, pressure generation portions A12 are arranged with neighboring each other in a matrix in the vicinity of an acute corner C of the parallelogram near to the actuator unit 255b. In the other additional region P13, pressure generation portions A13 are arranged with neighboring each other in a matrix in the vicinity of an acute corner D of the parallelogram far from the actuator unit 255b.

[0105] Therefore, as illustrated in FIG. 20, the pressure generation portions A12 of the additional region P12 of the actuator unit 255a and the pressure generation portions A13 of the additional region P13 of the actuator unit 255b are disposed in a gap portion G between the pressure generation portions A11 of the basic region P11 provided in the actuator unit 255a and the pressure generation portions A11 of the basic region P11 provided in the neighboring actuator unit 255b. Thus, the head main body 201 can be provided with which ink can be ejected with no break through the longitudinal direction of the passage unit.

[0106] Besides, this embodiment also can bring about the same advantages as those of the above-described first embodiment. More specifically, since the two actuator units 255a and 255b are arranged along the longitudinal direction of the passage unit 204, even in case of a long passage unit 204, high accuracy can be obtained in positioning of the actuator units 255a and 255b to the passage unit 204. Therefore, good ink ejection performance can be obtained and the manufacture yield of ink-jet heads 201 can be remarkably improved. In addition, by sandwiching the piezoelectric sheets 241 to 243 between the common electrodes 234a and 234b and the individual electrodes 235a and 235b, the volume of each pressure chamber 210 can easily be changed by the piezoelectric effect. Besides, the piezoelectric sheets 241 to 243 including active layers can easily be manufactured because they are continuous flat layers. Further, since an actuator unit 221 of a unimorph structure is provided in which the piezoelectric sheets 244 and 245 near to each pressure chamber 210 are inactive and the piezoelectric sheets 241 to 243 far from each pressure chamber 210 are layers including

active layers, the change in volume of each pressure chamber 210 can be increased by the transversal piezoelectric effect, and lowering the voltage to be applied to the individual electrodes 235a and 235b and/or high integration of the pressure chambers 210 can be intended. Further, in the passage unit 204, since a large number of pressure chambers 210 neighboring each other are arranged in a matrix, the many pressure chambers 210 can be disposed at a high density within a relatively small size.

[0107] In this embodiment, two actuator units are arranged. But, three or more actuator units may be arranged of course. Arrangement of many actuator units can bring about a long ink-jet head. Such a long ink-jet head is advantageous because it can perform printing onto even a large-size paper at a high speed.

[0108] FIGS. 21A and 21B illustrate head main bodies 271 and 272 according to modifications of the second embodiment, in which four actuator units 261 (In FIGS. 21A and 21B, they are denoted by reference numerals 261a, 261b, 261c, and 261d, respectively, in order from the right) each constructed like an actuator unit 221 or 255 are arranged in line on and bonded to passage units 274 having, near their both ends, ink supply ports 273. Such an actuator unit 261, like an actuator unit 221 or 255, can be used in common to passage units different in length, e.g., from a relatively short passage unit as illustrated in FIG. 11 to a long passage unit as illustrated in FIG. 21A. Thus, such an actuator unit is high in applicability as a component and this can reduce the manufacture cost.

[0109] In the head main bodies 201 and 271 as illustrated in FIGS. 11 and 21A, actuator units are arranged on a passage unit in a straight line with being aligned in the lateral direction of the passage unit. However, as in a head main body 272 illustrated in FIG. 21B for example, actuator units 261a, 261b, 261c, and 261d may be arranged in a zigzag form. But, from the viewpoint of making an ink-jet head compact, the arrangement as illustrated in FIG. 11 or 21A is preferable in which actuator units are arranged in a straight line along the longitudinal direction of the passage unit with being regularly aligned in the lateral direction of the passage unit. Particularly in case of the arrangement of FIG. 11 or 21A, the width of the ink-jet head can be made small. Therefore, when two or more ink-jet heads are arranged along their width to be supplied with inks of different colors for multicolor printing, they can be disposed within a compact space. This is further advantageous because occurrence of a shear in color of an image can be lessened even when a paper runs in an oblique state upon printing.

[0110] Next, a third embodiment of the present invention will be described. FIG. 22 is a plan view of a head main body of an ink-jet head according to this embodiment. In the ink-jet head and ink-jet printer according to this embodiment, since the parts other than the head main body is similar to that of the above-described first embodiment, the detailed description thereof is omitted

here.

[0111] Referring to FIG. 22, a head main body 301 of an ink-jet head according to this embodiment has a rectangular shape in a plan view extending in one direction. The head main body 301 includes a passage unit 304 in which a large number of pressure chambers 310 and a large number of ink ejection ports 308 are formed as will be described later. On the upper face of the passage unit 304, four regular-hexagonal actuator units 321 (In FIG. 22, they are denoted by reference numerals 321a, 321b, 321c, and 321d, respectively, in order from the right) are arranged in two lines in a zigzag manner and they are bonded to the upper face of the passage unit 304. Each actuator unit 321 is disposed so that its opposed parallel sides (upper and lower sides) extend along the longitudinal direction of the head main body 301. Each neighboring actuator units 321 are disposed so that their oblique sides is to be close to each other and have overlapping portions in the lateral direction of the passage unit.

[0112] Referring to FIG. 23 that is a view of the passage unit 304 at the reverse angle to FIG. 22 (a view from the printing face side), four hexagonal ink ejection regions R2 are provided in the lower face of the passage unit 304 to correspond to the respective regions where the actuator units 321 are disposed. A large number of small-diameter ink ejection ports 308 are arranged in the surface of each ink ejection region R2. A base block 302 is disposed on the upper face of the head main body 301. A pair of ink reservoirs 303 each having a slender shape along the longitudinal direction of the head main body 301 is provided in the base block 302. An opening 303a is formed in the upper face of the base block 302 at one end of each ink reservoir 303. Each opening 303a is connected with a not-illustrated ink tank, as a result, each ink reservoir 303 is always filled up with ink.

[0113] FIG. 24 is a sectional view illustrating the internal construction of the passage unit 304. Referring to FIG. 24, manifold channels 305 as ink supply sources are formed in the passage unit 304. Each manifold channel 305 communicates with an ink reservoir 303 through the corresponding opening 305a formed in the upper face of the passage unit 304. Each opening 305a is preferably provided with a filter for catching dust and dirt contained in ink.

[0114] Each manifold channel 305 branches at its opening 305a to supply ink to a number of pressure chambers 310 as described later. When each hexagonal ink ejection region R2 illustrated in FIG. 23 is evenly divided vertically in FIG. 23 into two regions, one manifold channel 305 is formed so as to correspond to one of the two regions. Eight manifold channels 305 are provided and each of them is so designed in shape as to distribute and supply ink to all pressure chambers 310 included in the corresponding region.

[0115] The ink ejection port 308 being in one half region in the lateral direction of the passage unit communicates with one of the ink reservoirs 303 in a pair

through a manifold channel 305. The ink ejection port 308 being in the other half region in the lateral direction of the ink-jet head communicates with the other ink reservoir 303. By thus arranging the manifold channels 305, the openings 305a, and the ink reservoirs 303, two printing modes can be realized: (1) a mode in which the ink reservoirs 303 in the pair are supplied with ink of the same color to perform monochrome high-resolution printing; and (2) a mode in which the ink reservoirs 303 in the pair are supplied with ink of different colors to perform two-color printing with the single head main body 301. This is a wide-usable construction.

[0116] Referring to FIG. 26, each ink ejection port 308 is made into a tapered nozzle. The ink ejection port 308 communicates with a manifold channel 305 through a pressure chamber 310 having a nearly rhombic shape in a plan view and an aperture 312. In this construction, ink is supplied to the manifold channel 305 through the ink reservoir 303 and further supplied from the manifold channel 305 to the pressure chamber 310 through the aperture 312. By driving an actuator unit 321 as will be described later, jet energy is applied to ink in the pressure chamber 310 to jet ink through the ink ejection port 308.

[0117] FIG. 25 illustrates a detailed construction of the region denoted by reference E in FIG. 24. As apparent from FIG. 25, in a region of the upper face of the passage unit 304 corresponding to an ink ejection region R2, a large number of pressure chambers 310 are arranged in a matrix to neighbor each other. Since the pressure chambers 310 are formed at a different level from that of the apertures 312 as illustrated in FIG. 26, an arrangement is possible in which each aperture 312 connected with a pressure chamber 310 overlaps another pressure chamber 310. As a result, a highly dense arrangement of the pressure chambers 310 can be realized and this may contribute a decrease in size of the head main body 301 and an increase in resolution of an image to be formed.

[0118] FIG. 26 illustrates a specific construction of a passage from a manifold channel 305 to an ink ejection port 308. Referring to FIG. 26, the passage unit 304 is laminated with nine sheet materials in total, i.e., a cavity plate 322, a base plate 323, an aperture plate 324, a supply plate 325, manifold plates 326, 327, and 328, a cover plate 329, and a nozzle plate 330. The above-described actuator units 321 are bonded to the upper face of the passage unit 304 to constitute a head main body 301. The detailed construction of each actuator unit 321 will be described later.

[0119] A rhombic opening is formed in the cavity plate 322 to form a pressure chamber 310. A tapered ink ejection port 308 is formed in the nozzle plate 330 with a press. Communication holes 351 are formed through each of the plates 323 to 329 between the plates 322 and 330. The pressure chamber 310 communicates with the ink ejection port 308 through the communication holes 351. An aperture 312 as an elongated hole is

formed in the aperture plate 324. One end of the aperture 312 is connected with an end portion of the pressure chamber 310 (opposite to the end portion connecting with the ink ejection port 308) through a communication hole 352 formed in the base plate 323. The aperture 312 is for properly controlling the amount of ink to be supplied to the pressure chamber 310 and preventing too much or too little ink from being jetted through the ink ejection port 308. A communication hole 353 is formed in the supply plate 325. The communication hole 353 connects the other end of the aperture 312 with the manifold channel 305.

[0120] Each of the nine plates 322 to 330 constituting the passage unit 304 is made of metal. The above-described pressure chamber 310, aperture 312, and communication holes 351, 352, and 353 are formed by selectively etching each metallic plate using a mask pattern. The nine plates 322 to 330 are put in layers and bonded to each other with being positioned to each other so that the passage as illustrated in FIG. 26 is formed therein.

[0121] Next, the structure of each actuator unit 321 will be described. Referring to FIG. 27, the actuator unit 321 includes five piezoelectric sheets 341 to 345 having the same thickness of about 15 m. These piezoelectric sheets 341 to 345 are made into continuous flat layers. One actuator unit 321 is disposed to extend over many pressure chambers 310 formed in one ink ejection region R2 of the head main body 301. This can realize a highly dense arrangement of individual electrodes 335a and 335b. Each of the piezoelectric sheets 341 to 345 is made of a lead zirconate titanate (PZT)-base ceramic material having ferroelectricity.

[0122] Between the first and second piezoelectric sheets 341 and 342 from the top, an about 2 m-thick common electrode 334a is interposed formed on substantially the whole of the lower and upper faces of the piezoelectric sheets. Also, between the third and fourth piezoelectric sheets 343 and 344, an about 2 m-thick common electrode 234b is interposed. On the upper face of the first piezoelectric sheet 341, an about 1 m-thick individual electrode 335a is formed to correspond to each pressure chamber 310. As illustrated in FIG. 24, the individual electrode 335a has a similar shape to that of the pressure chamber 310 in a plan view though the individual electrode 335a is somewhat smaller than the pressure chamber 310. The individual electrode 335a is disposed such that the center of the individual electrode 335a coincides with the center of the corresponding pressure chamber 310. Further, between the second and third piezoelectric sheets 342 and 343, an about 2 m-thick individual electrode 335b is interposed formed like the individual electrode 335a. No electrode is provided between the fourth and fifth piezoelectric sheets 344 and 345, and on the lower face of the fifth piezoelectric sheet 345. Each of the electrodes 334a, 334b, 335a, and 335b is made of, e.g., an Ag-Pd-base metallic material.

[0123] The common electrodes 334a and 334b are grounded in a not-illustrated region. Thus, the common electrodes 334a and 334b are kept at the ground potential at a region corresponding to any pressure chamber 310. In order that the individual electrodes 335a and 335b in each pair corresponding to a pressure chamber 310 can be controlled in potential independently of another pair, they are connected with a suitable driver IC (not illustrated) through a lead provided separately for each pair of individual electrodes 335a and 335b.

[0124] In the head main body 301, the piezoelectric sheets 341 to 345 are to be polarized in their thickness. That is, the actuator unit 321 has a so-called unimorph structure in which the upper (i.e., distant from the pressure chamber 310) three piezoelectric sheets 341 to 343 are layers including active layers, and the lower (i.e., near the pressure chamber 310) two piezoelectric sheets 344 and 345 are made into inactive layers.

[0125] In this structure, when the individual electrodes 335a and 335b in a pair are set at a positive or negative predetermined potential, if the polarization is in the same direction as the electric field for example, the portion (an active layer, i.e., a pressure generation portion) in the piezoelectric sheets 341 to 343 sandwiched by the common and individual electrodes contracts perpendicularly to the polarization. On the other hand, since the inactive piezoelectric sheets 344 and 345 are influenced by no electric field, they do not contract in themselves. Thus, a difference in strain perpendicular to the polarization is produced between the upper piezoelectric sheets 341 to 343 and the lower piezoelectric sheets 344 and 345. As a result, the whole of the piezoelectric sheets 341 to 345 is ready to deform into a convex shape toward the inactive side (unimorph deformation). At this time, since the lower face of the lowermost piezoelectric sheet 345 is fixed to the upper face of the partition partitioning pressure chambers 310, the piezoelectric sheets 341 to 345 deform into a convex shape toward the pressure chamber 310 side to decrease the volume of the pressure chamber 310. As a result, the pressure of ink is raised and ink is thereby ejected through the ink ejection port 308. After this, when application of the driving voltage to the individual electrodes 335a and 335b is stopped, the piezoelectric sheets 341 to 345 return to the original shape and the pressure chamber 310 also returns to its original volume. Thus, the pressure chamber 310 sucks ink therein through the manifold channel 305.

[0126] To manufacture each actuator unit 321, first, ceramic green sheets to be piezoelectric sheets 341 to 345 are put in layers and then baked. At this time, a metallic material to be individual electrodes 335a or a common electrode 334a or 334b is printed into a pattern on each ceramic green sheet at need. After this, a metallic material to be individual electrodes 335a is formed by plating on the whole of the upper face of the first piezoelectric sheet 341 and then unnecessary portions of the material are removed by laser patterning. Alternatively,

a metallic material to be individual electrodes 335a is deposited using a mask having openings at portions corresponding to the respective individual electrodes 335a.

[0127] The actuator unit 321 thus manufactured is very brittle because it is made of ceramic. In particular, since corners of the actuator unit 321 are very easy to be broken off, very delicate handling is required upon manufacture and assembling in order that any corner must not be brought into contact with another component.

[0128] However, as illustrated in FIG. 28A that is a plan view of the actuator unit 321, in the ink-jet head according to this embodiment, the actuator unit 321 has a substantially regular-hexagonal profile. Any of six straight portions (sides) L1 to L6 included in this profile is connected with a neighboring straight portion L at about 120°. As a result, since any of the six corners (portions of each neighboring straight portions L crossing each other) 1 to 6 is not acute, it is hard to be broken off. Therefore, the actuator unit 321 as an expensive precise component may not be easy to be broken in the middle of manufacture process. This may contribute a reduction of manufacture cost.

[0129] The above effect is not obtained only when any of the corners 1 to 6 is formed into 120°. If a corner n is formed into 90° or more, the corner n is hard to be broken off. Therefore, for making any of the six corners 1 to 6 hard to be broken off, it suffices that any of the six straight portions L1 to L6 is connected with a neighboring straight portion L at the right angle or an obtuse angle (the minimum value of the angles 1 to 6 at the crossing portions is 90° or more). The hexagonal profile can freely be changed as far as the above condition is satisfied. FIG. 28B illustrates an actuator unit 355 as an example in which the above condition is satisfied.

[0130] Besides, this embodiment also can bring about the same advantages as those of the above-described first embodiment. More specifically, since the four actuator units 321 are arranged along the longitudinal direction of the passage unit 304, even in case of a long passage unit 304, high accuracy can be obtained in positioning of the actuator units 321 to the passage unit 304. Therefore, good ink ejection performance can be obtained and the manufacture yield of ink-jet heads 301 can be remarkably improved. Besides, by sandwiching the piezoelectric sheets 341 to 343 between the common electrodes 334a and 334b and the individual electrodes 335a and 335b, the volume of each pressure chamber 310 can easily be changed by the piezoelectric effect. Besides, the piezoelectric sheets 341 to 343 including active layers can easily be manufactured because they are continuous flat layers. Besides, since an actuator unit 321 of a unimorph structure is provided in which the piezoelectric sheets 344 and 345 near to each pressure chamber 310 are inactive and the piezoelectric sheets 341 to 343 far from each pressure chamber 310 are layers including active layers, the change in volume of each pressure chamber 310 can be increased by the

transversal piezoelectric effect, and lowering the voltage to be applied to the individual electrodes 335a and 335b and/or high integration of the pressure chambers 310 can be intended. Further, in the passage unit 304, since a large number of pressure chambers 310 neighboring each other are arranged in a matrix, the many pressure chambers 310 can be disposed at a high density within a relatively small size.

[0131] In the present invention, the profile of each actuator unit is not limited to a hexagon. That is, the number of straight portion L may be not six but five, seven, eight, or more. Hereinafter, modifications in profile of each actuator unit will be described with reference to FIGS. 28 to 30. In the below modifications, the same components as in the above-described third embodiment are denoted by the same reference numerals as in the third embodiment, respectively.

[0132] FIG. 29A is a plan view of a head main body in which each actuator unit is made into a heptagonal shape. FIG. 29B is a plan view of an actuator unit included in the head main body of FIG. 29A. As apparent from FIGS. 29A and 29B, in this modification, the components of the head main body 361 other than the actuator units 362 (In FIGS. 29A, they are denoted by reference numerals 362a, 362b, 362c, and 362d, respectively, in order from the right) are constructed like those of the head main body 301 of the third embodiment.

[0133] Referring to FIG. 29B, each actuator unit 362 has its profile in which one corner of a hexagon according to the above-described embodiment has been cut off along a straight line. As a result, the number of straight portion L is seven (L8 to L14), and as for the angle of each corner, 8 to 12 are about 120 and 13 and 14 are about 150 .

[0134] FIG. 30A is a plan view of a head main body in which each actuator unit is made into an octagonal shape. FIG. 30B is a plan view of an actuator unit included in the head main body of FIG. 30A. As apparent from FIGS. 30A and 30B, in this modification, the components of the head main body 371 other than the actuator units 372 (In FIGS. 30A, they are denoted by reference numerals 372a, 372b, 372c, and 372d, respectively, in order from the right) are constructed like those of the head main body 301 of the third embodiment.

[0135] Referring to FIG. 30B, each actuator unit 372 has its profile in which two corners of a hexagon according to the above-described embodiment has been cut off along straight lines. As a result, the number of straight portion L is eight (L15 to L22), and as for the angle of each corner, 15, 16, 19, and 20 are about 120 and 17, 18, 21, and 22 are about 150 . In the above-described two modifications, since the angle of each corner of each cut-off portion is 150 , which is larger than that of the above-described hexagonal actuator unit 321, the corner is harder to be broken off than that of the above-described hexagonal actuator unit 321.

[0136] FIG. 31A is a plan view of a head main body in which two interconnecting portions of neighboring

straight portions L in the actuator unit of the above-described third embodiment have been made into rounded portions F. FIG. 31B is a plan view of an actuator unit included in the head main body of FIG. 31A. As apparent from FIGS. 31A and 31B, in this modification, the components of the head main body 381 other than the actuator units 382 (In FIGS. 31A, they are denoted by reference numerals 382a, 382b, 382c, and 382d, respectively, in order from the right) are constructed like those of the head main body 301 of the second embodiment.

[0137] Referring to FIG. 31B, each actuator unit 382 has six straight portions L23 to L28. Two interconnecting portions of neighboring straight portions L (L23 and L28, and L25 and L26) in the actuator unit 382 are made into rounded portions F, where neighboring straight portions L are smoothly interconnected. Each rounded portion F is very hard to be broken off. Also in this case, the angle between each neighboring straight portions L, including two straight portions on both sides of each rounded portion F, (23 to 27), is more than 90 (about 120).

[0138] Next, the fourth embodiment of the present invention will be described with reference to FIG. 32. In the ink-jet head and ink-jet printer according to this embodiment, since the parts other than the head main body is similar to that of the above-described first embodiment, the detailed description thereof is omitted here.

[0139] A head main body 401 as illustrated in FIG. 32 includes a passage unit 404 in which a large number of pressure chambers and a large number of ink ejection ports are formed like the above-described embodiments. Onto the upper face of the passage unit 404, two parallelogrammic actuator units 421 (In FIG. 32, the right and left ones are denoted by reference numerals 421a and 421b, respectively) are bonded to neighbor each other. Each actuator unit 421 is disposed so that its one side B extends along the longitudinal direction of the head main body 401. The neighboring actuator units 421 are so disposed as to be aligned with each other along the lateral direction of the head main body 401 with their oblique sides C being close to each other. Two actuator units 421 partially overlap each other along the lateral direction of the passage unit 404. An ink supply port 402 is open in the upper face of the passage unit 404. The ink supply port 402 is connected with an ink supply source through a not-illustrated passage.

[0140] Onto the upper face of each actuator unit 421, an FPC 436 is bonded for supplying electric signals to individual and common electrodes in the actuator unit 421. Onto each FPC 436, a driver IC 432 is bonded as a driving circuit for generating driving signals to be supplied to the individual electrodes in the corresponding actuator unit 421. Each FPC 436 is electrically connected with a control unit 440 including CPU, RAM, and ROM. The control unit 440 supplies printing data to each driver IC 432. Each driver IC 432 generates driving signals for individual electrodes on the basis of the printing data.

[0141] Two regions P21 and P22 are provided in each

actuator unit 421. Of them, the basic region P21 has a parallelogrammic shape having its sides in parallel with the respective sides of the corresponding actuator unit 421. The basic region P21 has its width somewhat shorter than the side B of the actuator unit 421 and its length of about 3/4 the side C of the actuator unit 421. In FIG. 32, the basic region P21 is provided in an upper portion of the actuator unit 421. The additional region P22 has a parallelogrammic shape having its sides in parallel with the respective sides of the corresponding actuator unit 421. The additional region P22 has the same width as the basic region P21 and is disposed on the lower side of the basic region P21. The additional region P22 is divided into two sub-regions P22a and P22b each having a parallelogrammic shape having its sides in parallel with the respective sides of the actuator unit 421. The sub-region P22a has its width of about 1/5 the side B of the actuator unit 421 and its length of about 1/5 the side C of the actuator unit 421. In FIG. 32, the sub-region P22a is in the vicinity of the lower left acute portion of the actuator unit 421. The sub-region P22b has its width of about 3/5 the side B of the actuator unit 421 and its length of about 1/5 the side C of the actuator unit 421. In FIG. 32, the sub-region P22b is on the lower side of the basic region P21 and on the right side of the sub-region P22a.

[0142] In each of the basic region P21 and the sub-regions P22a and P22b of the additional region P22, a large number of pressure generation portions are arranged with neighboring each other in a matrix along the longitudinal direction of the passage unit 404 and along the side C of the parallelogram. Pressure chambers and ink passages including nozzles are formed in the passage unit 404 to correspond to the respective pressure generation portions.

[0143] When the two actuator units 421a and 421b each constructed as described above are arranged in line along the longitudinal direction of the passage unit 404 as illustrated in FIG. 32, a region (hatched region G in FIG. 32) where no pressure generation portions exist is formed near the seam portion between the actuator units 421a and 421b. When the only pressure generation portions in the basic region P11 are taken into consideration, the number of pressure generation portions along the lateral direction of the passage unit 404 in the vicinity of the seam portion is less than that in the portion other than the vicinity of the seam portion.

[0144] Hence, in this embodiment, utilizing the feature that the sub-region P22a of the additional region P22 provided on the lower side of the basic region P21 is provided to correspond to the region G where no pressure generation portions exist, near the seam portion, along the lateral direction of the passage unit 404, the control unit 440 controls each driver IC 432 upon printing so as to drive pressure generation portions in the basic region P21 and in the sub-region P22a of the additional region P22 and not to drive any pressure generation portion in the sub-region P22b of the additional region P22.

By this, since pressure generation portions in the actuator unit 421 are arranged in a region having substantially the same shape as in the actuator unit 221 of FIG. 18, the number of pressure generation portions along the passage unit 404 in the vicinity of the seam portion is the same as that in the other portion. That is, since the pressure generation portions of the sub-region P22a of the additional region P22 are disposed so as to correspond to the gap portion between the pressure generation portions of the basic region P21 provided in one actuator unit 421a and the pressure generation portions of the basic region P21 provided in the neighboring actuator unit 421b, the head main body 401 can be provided capable of printing with no break throughout the longitudinal direction of the passage unit, without providing any other actuator unit for ejecting ink through the gap portion. Further, since the pressure generation portion formation region in each actuator unit 421 has a similar shape to that of the actuator unit 421, problems of distortion, bend, or the like, of the actuator unit 421 is hard to arise.

[0145] As apparent from the above description, in this embodiment, ink passages may not be provided in the portion of the passage unit 404 corresponding to the sub-region P22b of the additional region P22.

[0146] The materials of each piezoelectric sheet and each electrode used in the above-described embodiments are not limited to the above-described ones. They can be changed to other known materials. The shapes in plan and sectional views of each pressure chamber, the arrangement of pressure chambers, the number of piezoelectric sheets including active layers, the number of inactive layers, etc., can be changed properly. Each piezoelectric sheet including active layers may differ in thickness from each inactive layer.

[0147] Besides, in the above-described embodiments, each actuator unit is constructed in which individual and common electrodes are provided on a piezoelectric sheet. But, such an actuator unit may not always be used bonded to the passage unit. Any other actuator unit can be used if it can change the volumes of the respective pressure chambers separately. Besides, in the above-described embodiments, pressure chambers are arranged in a matrix. But, the pressure chambers may be arranged in a line or lines. Further, although any inactive layer is made of a piezoelectric sheet in the above-described embodiment, the inactive layer may be made of an insulating sheet other than a piezoelectric sheet.

Claims

1. An ink-jet head comprising:

a passage unit (304) including a plurality of pressure chambers (310) each communicating with a nozzle (308) for ejecting ink, the plurality

of pressure chambers (310) being arranged along a plane to neighbour each other; and an actuator unit (321) fixed to a surface of the passage unit (304) for changing the volume of each of the pressure chambers (310), the actuator unit (321) being formed to extend along the pressure chambers (310), the actuator unit (321) including a plurality of pressure generation portions respectively corresponding to the pressure chambers (310), the actuator unit (321) having a profile with five or more straight portions (L1-L6), each of the straight portions (L1-L6) being connected with a neighboring straight portion (L1-L6) at one of the right angle and an obtuse angle.

2. The ink-jet head according to claim 1, wherein a plurality of actuator units (321) are arranged along the longitudinal direction of the passage unit.

3. The ink-jet head according to claim 1 or 2, wherein at least one of interconnecting portions (F) of the straight portions (L23-L28) is rounded.

FIG. 1

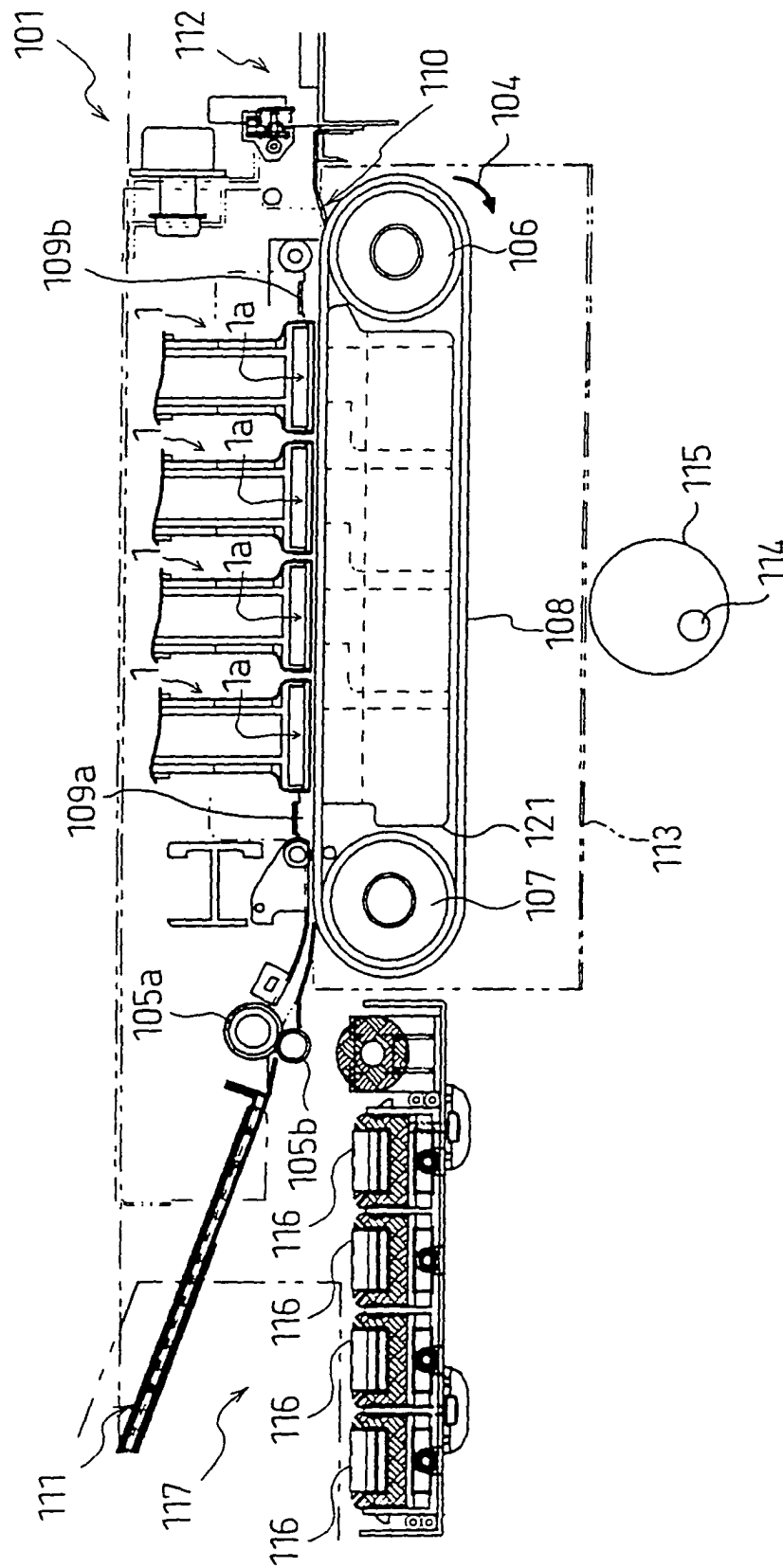


FIG. 2

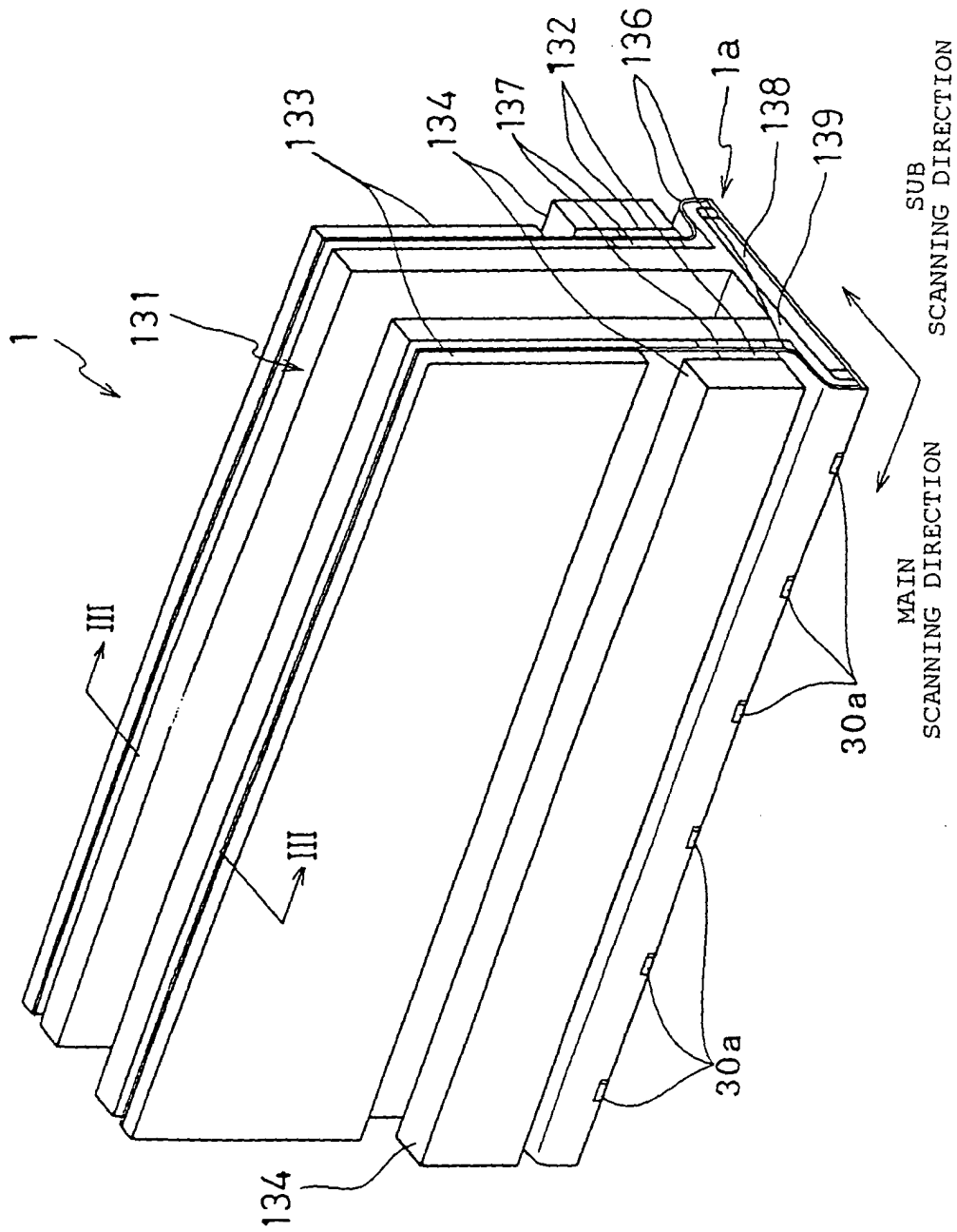


FIG. 3

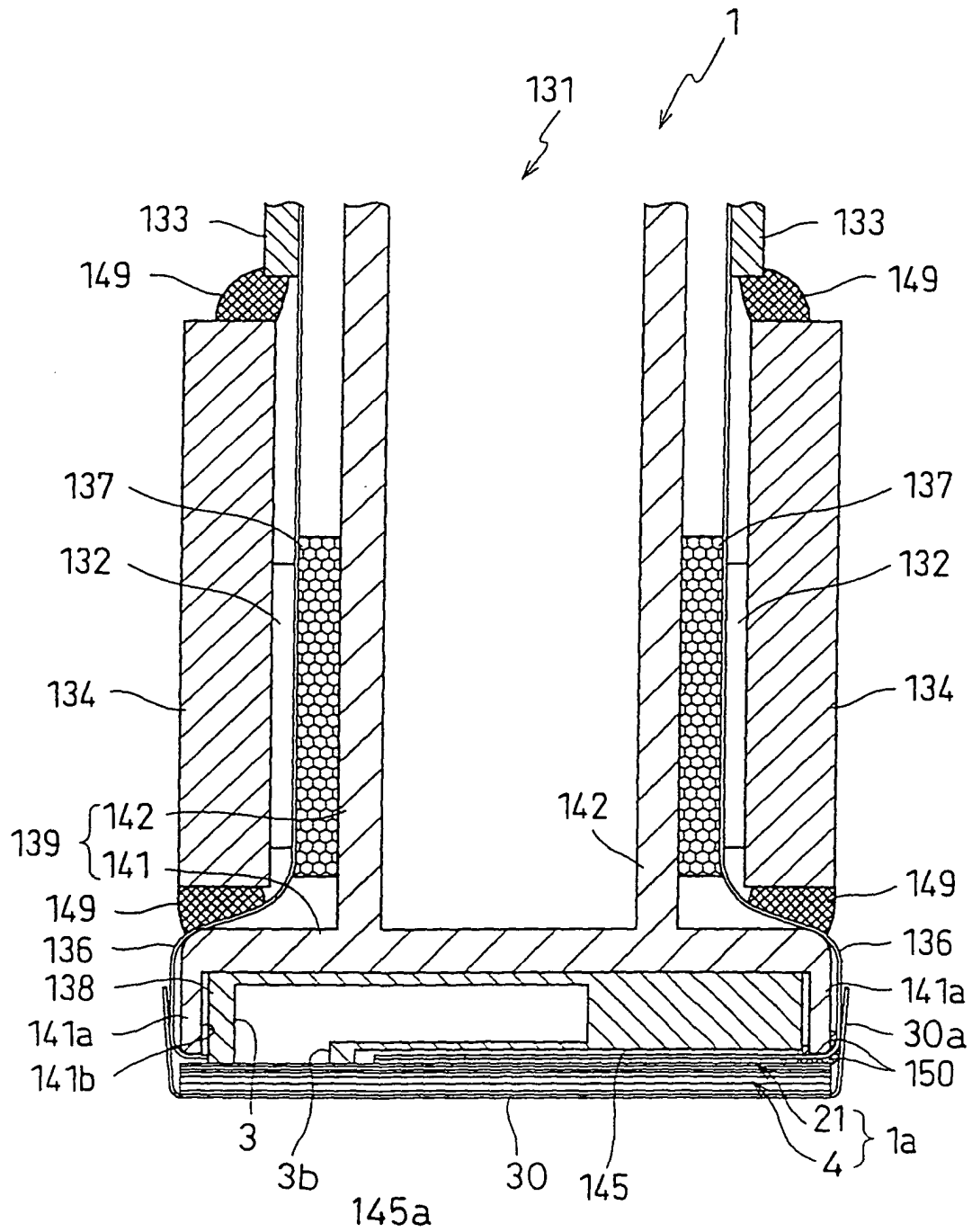


FIG. 4

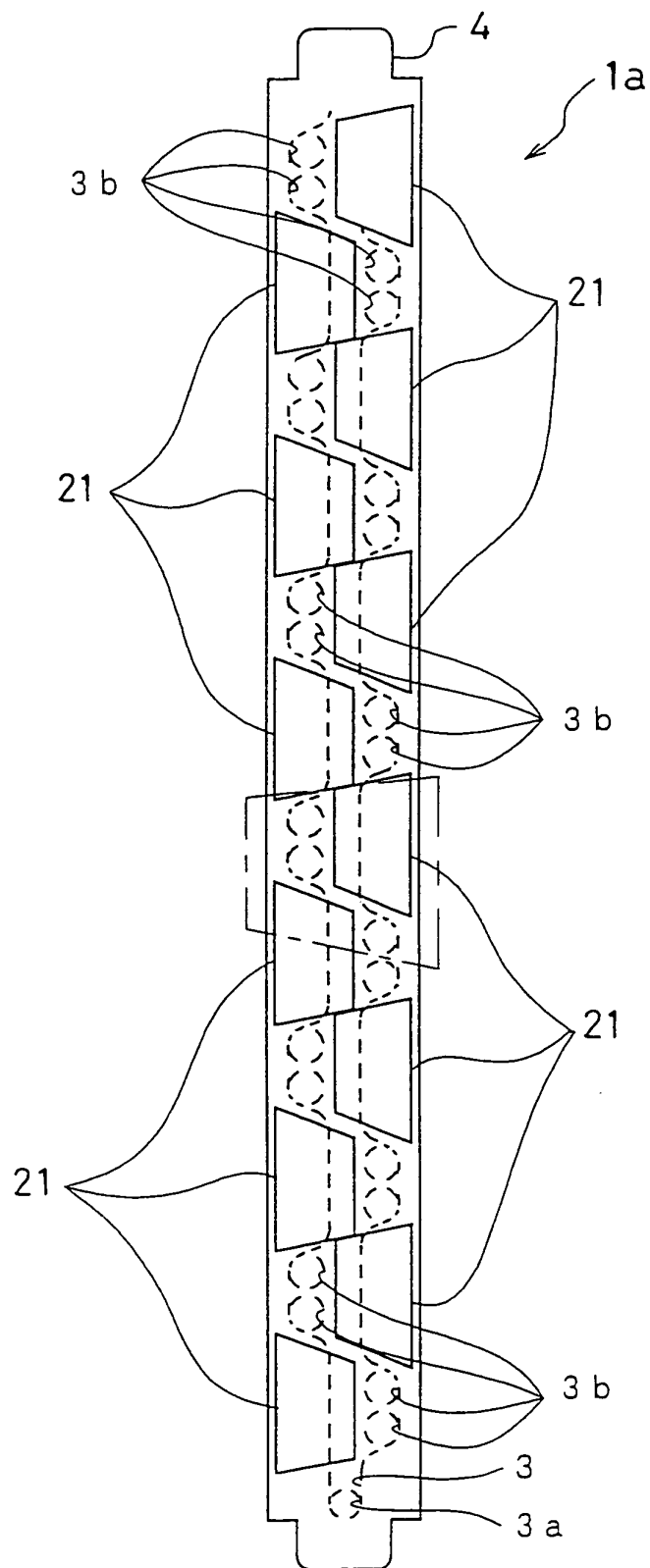


FIG. 5

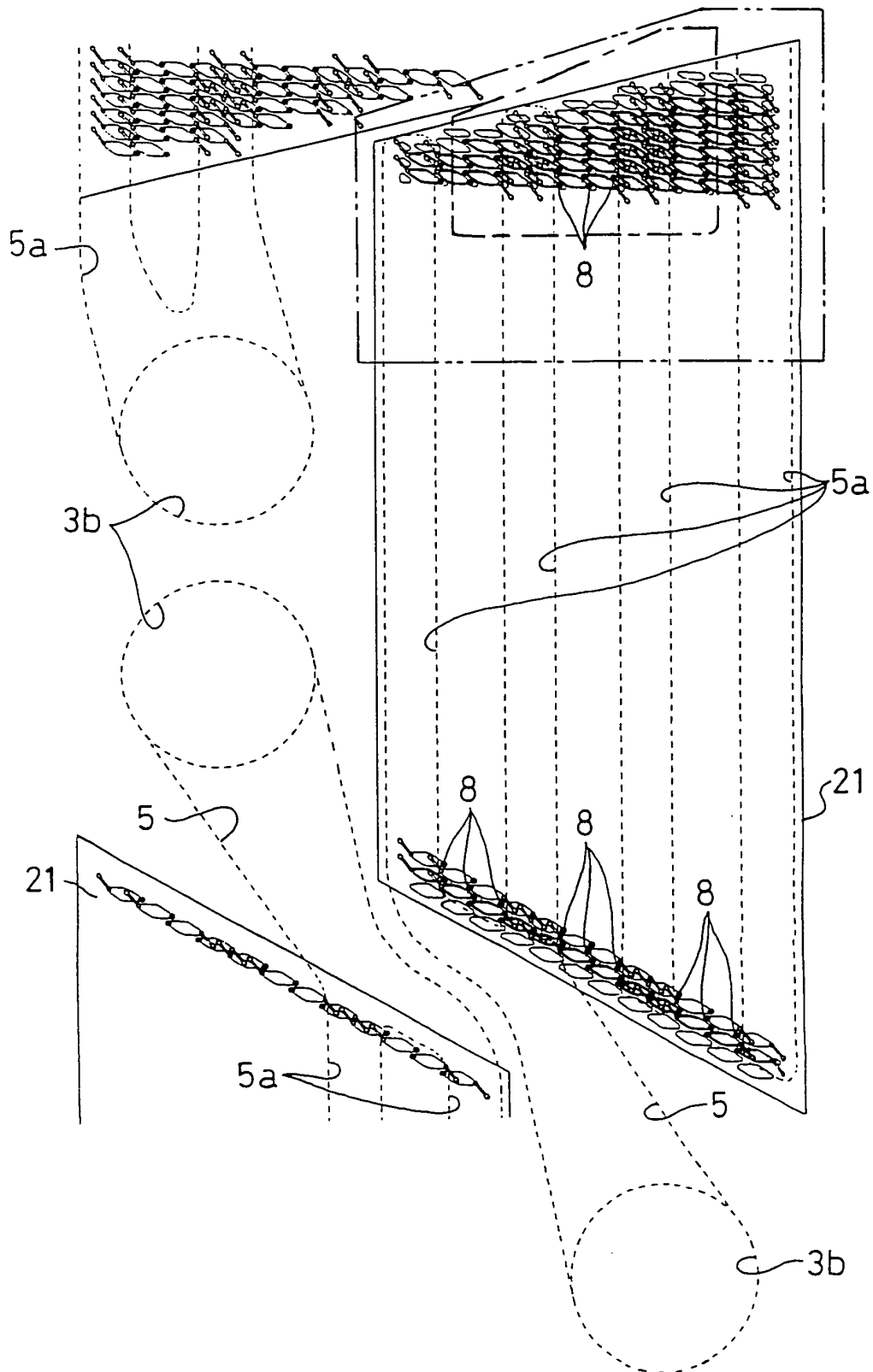


FIG. 6

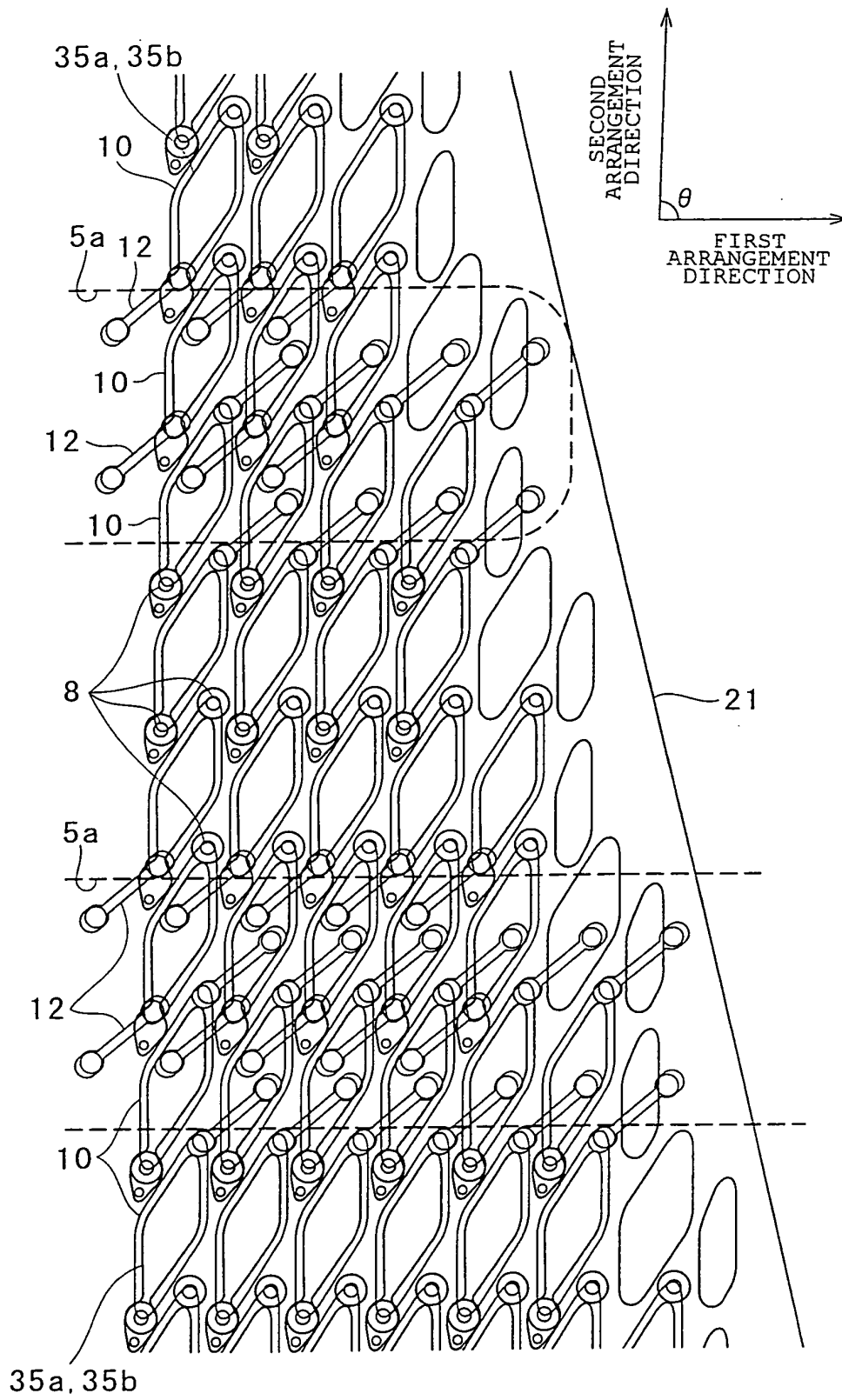


FIG. 7

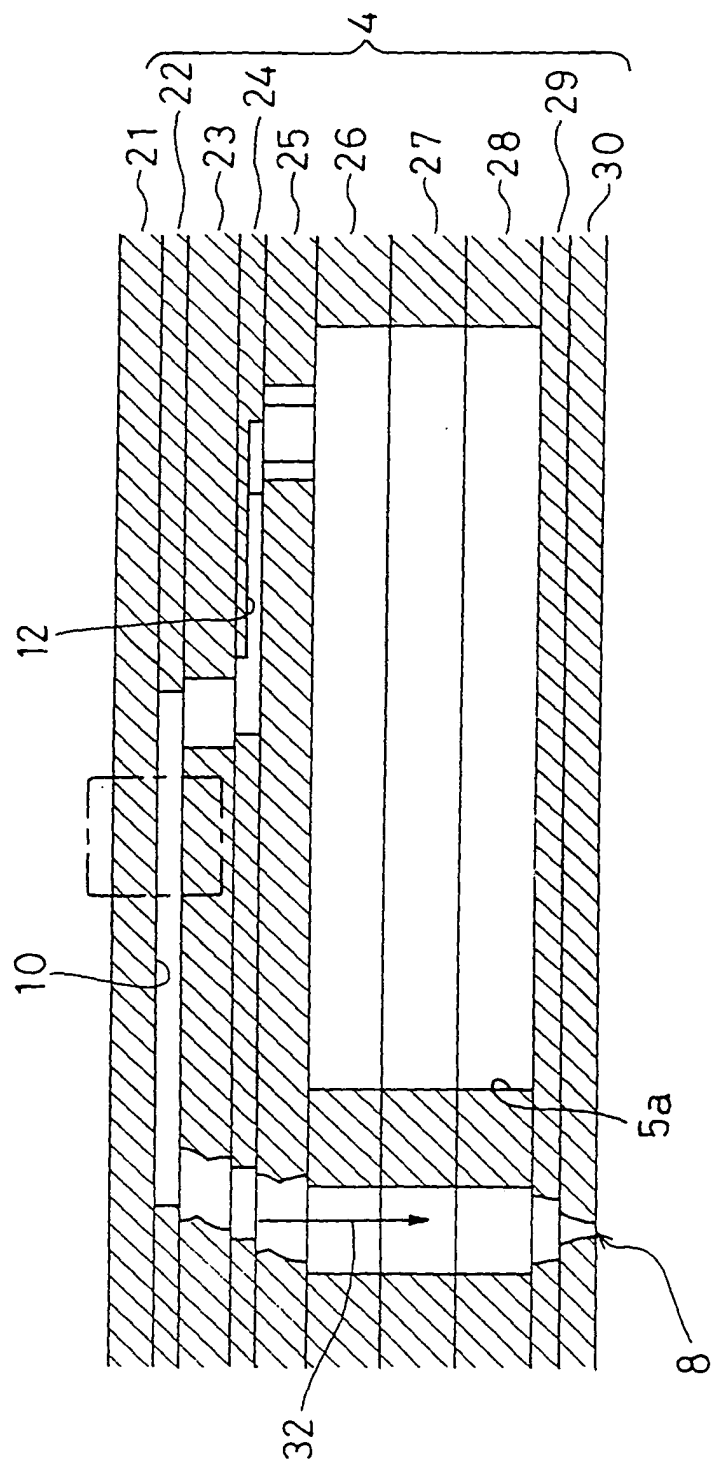


FIG. 8

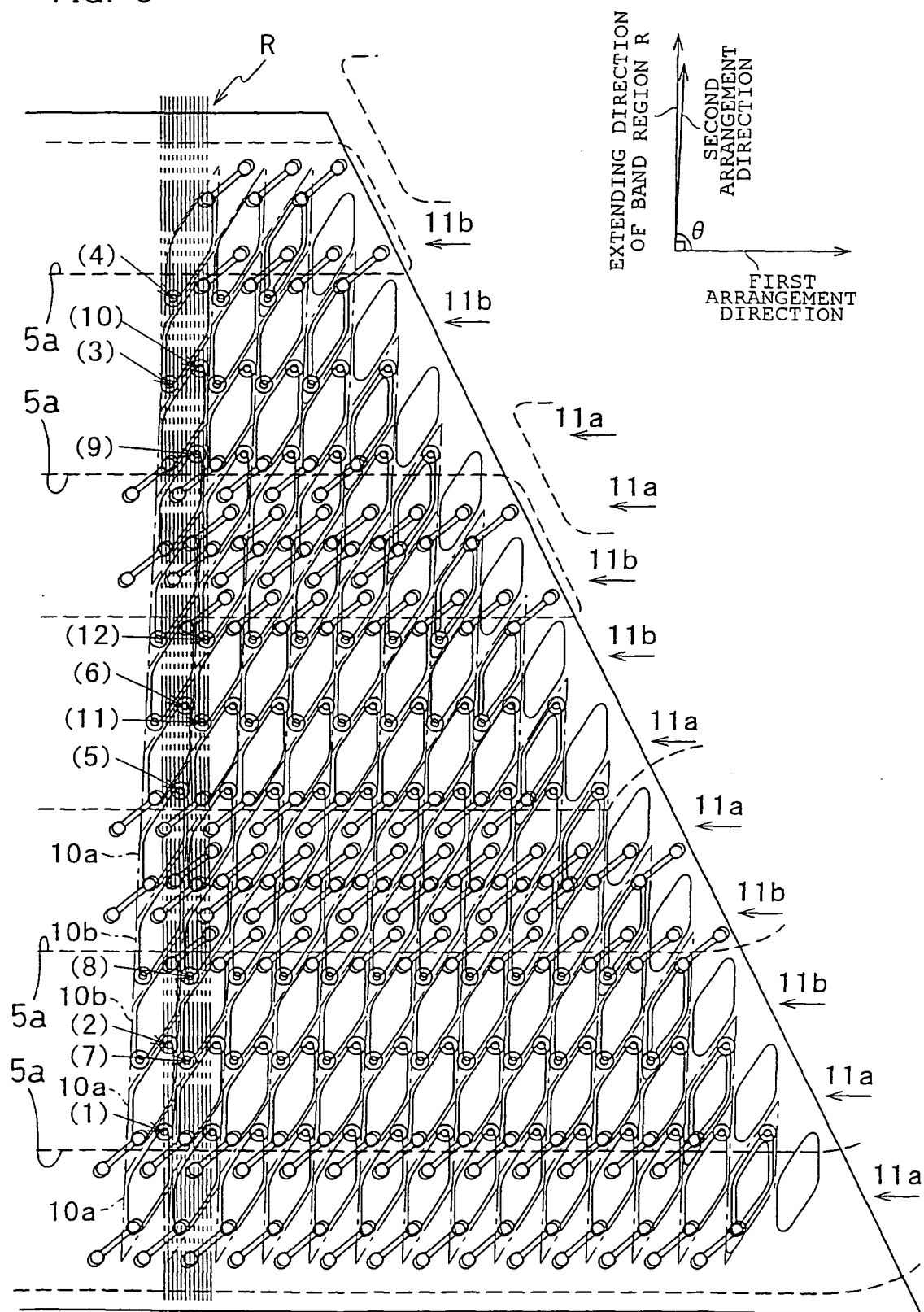


FIG. 9

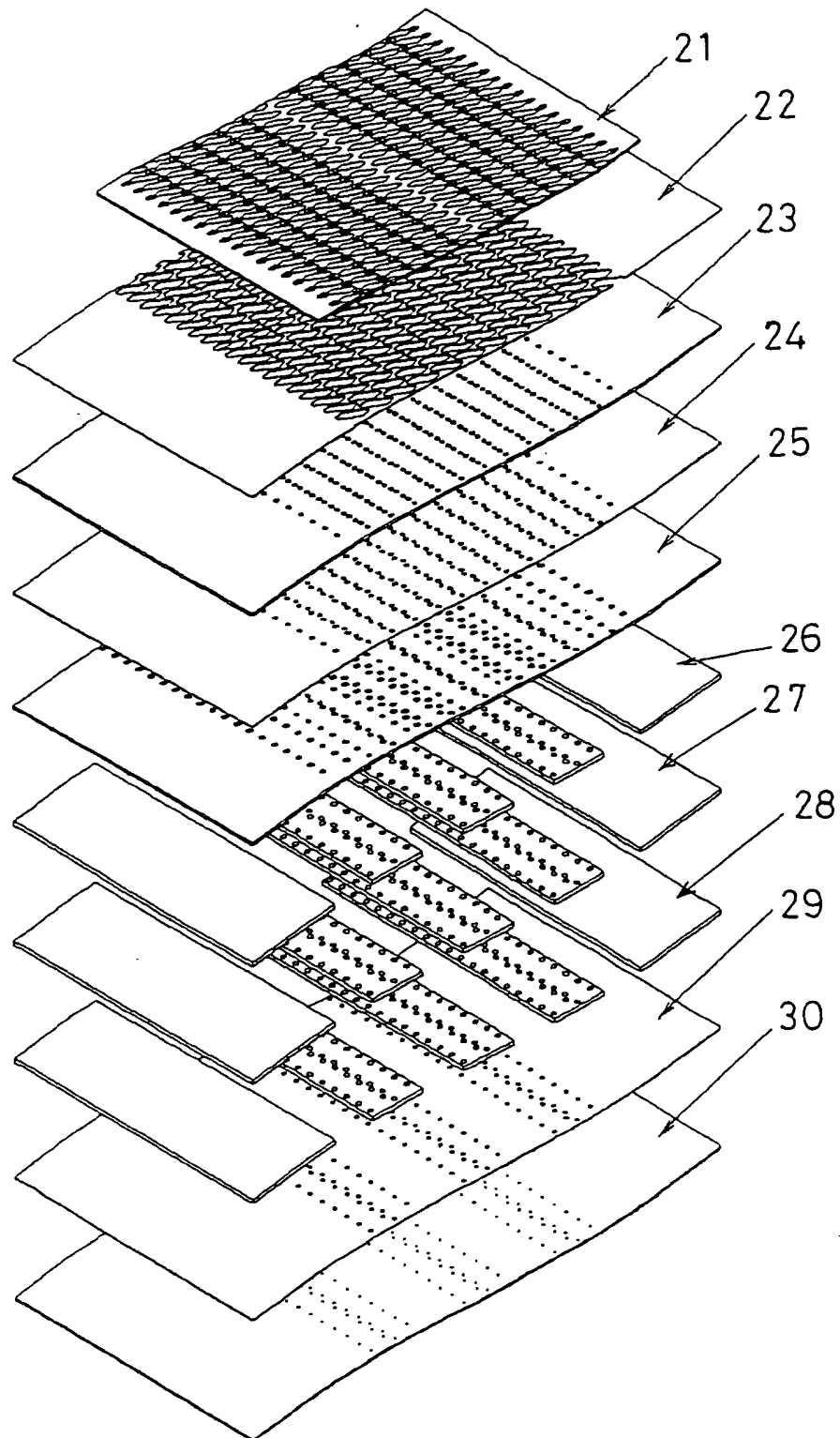


FIG. 10

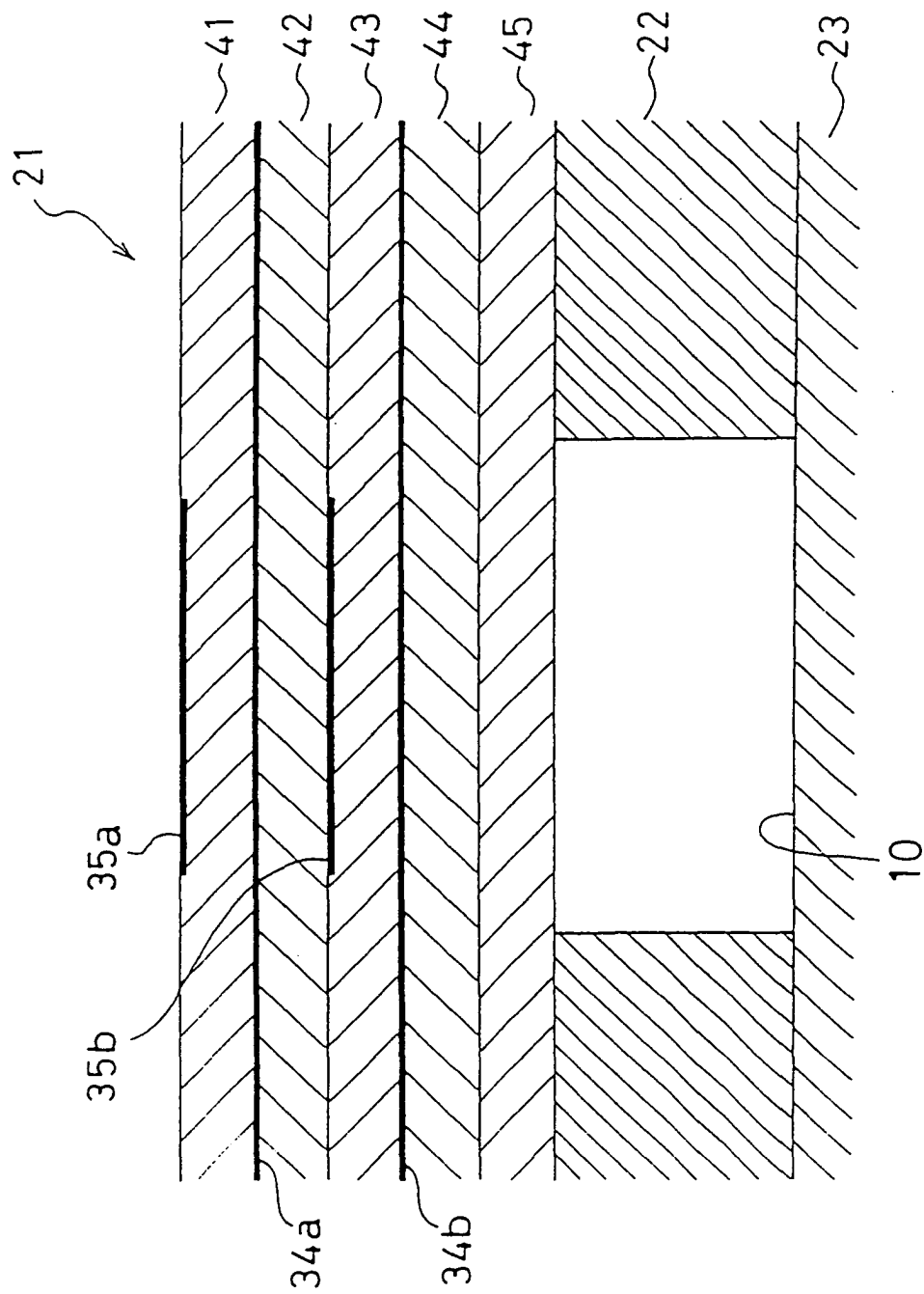


FIG. 11

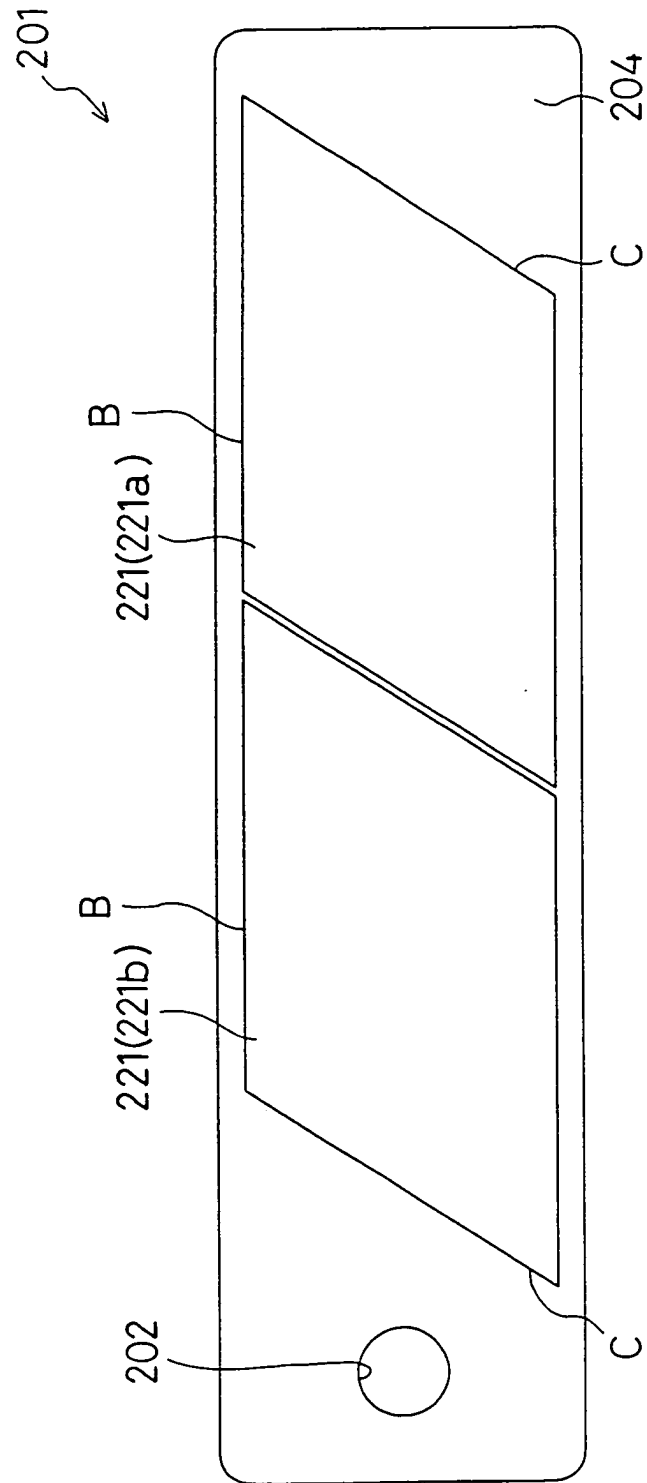


FIG. 12

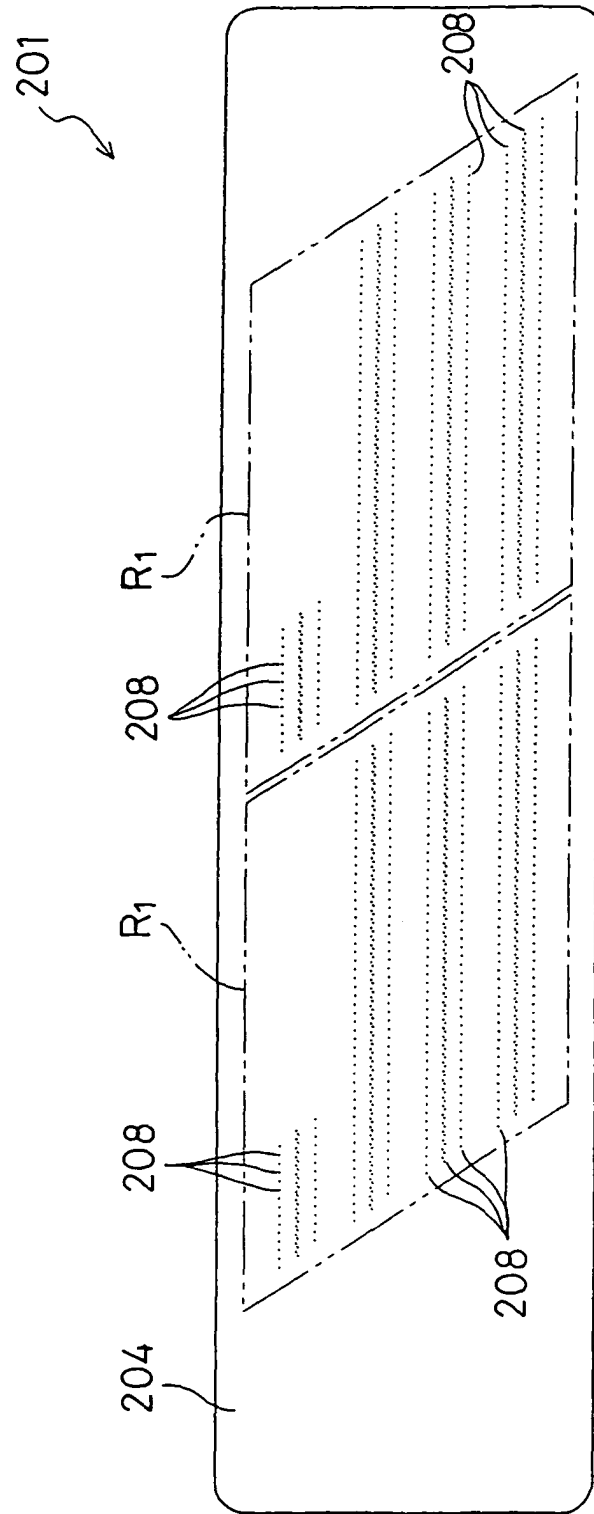


FIG. 13

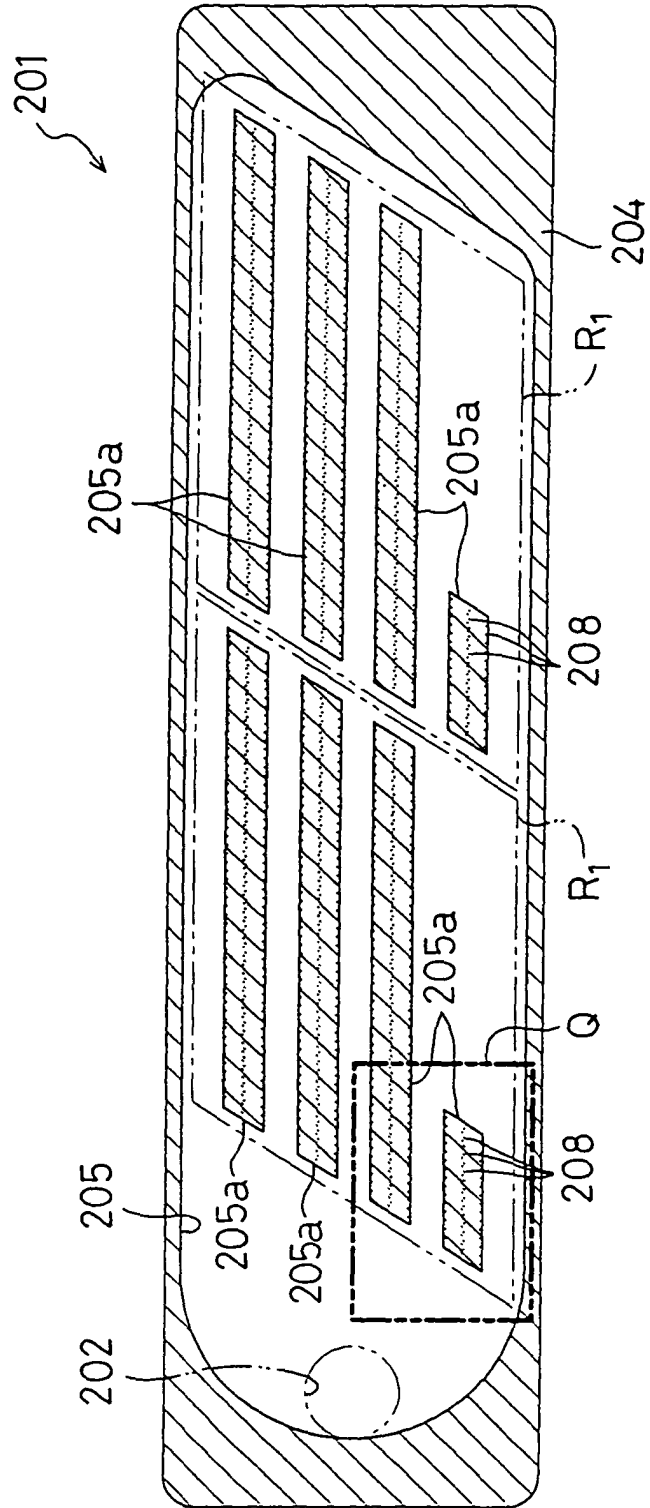


FIG. 14

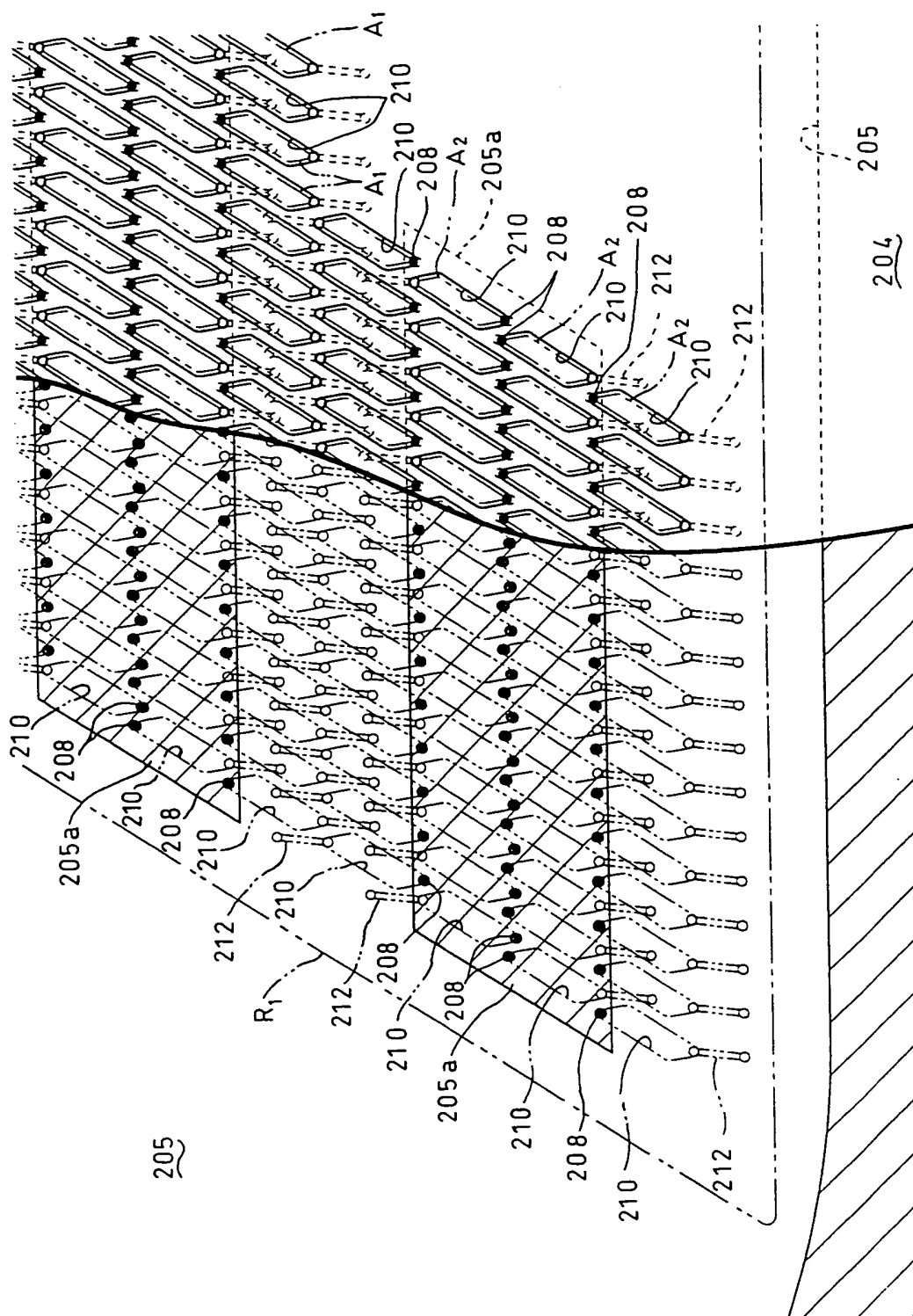


FIG. 15

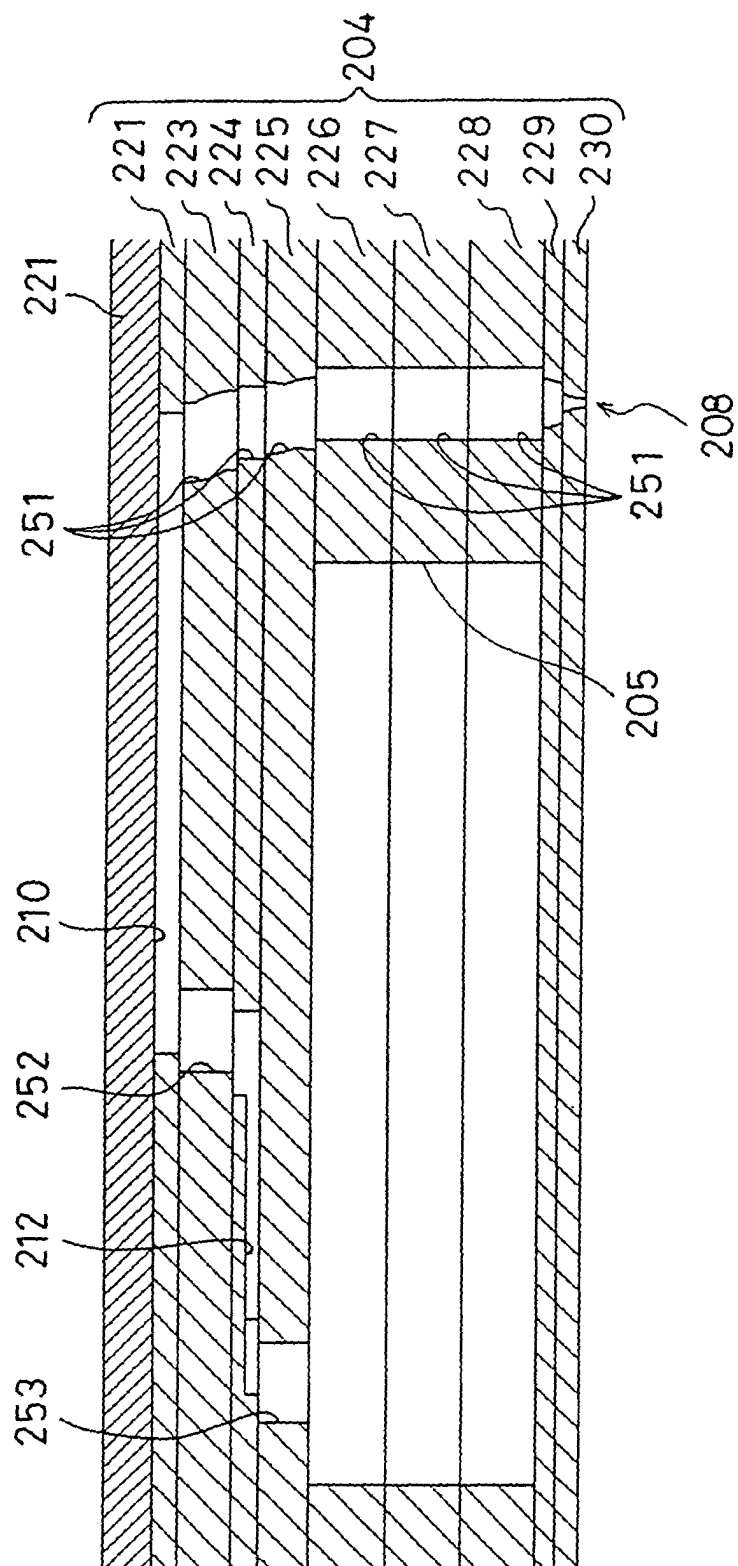


FIG. 16

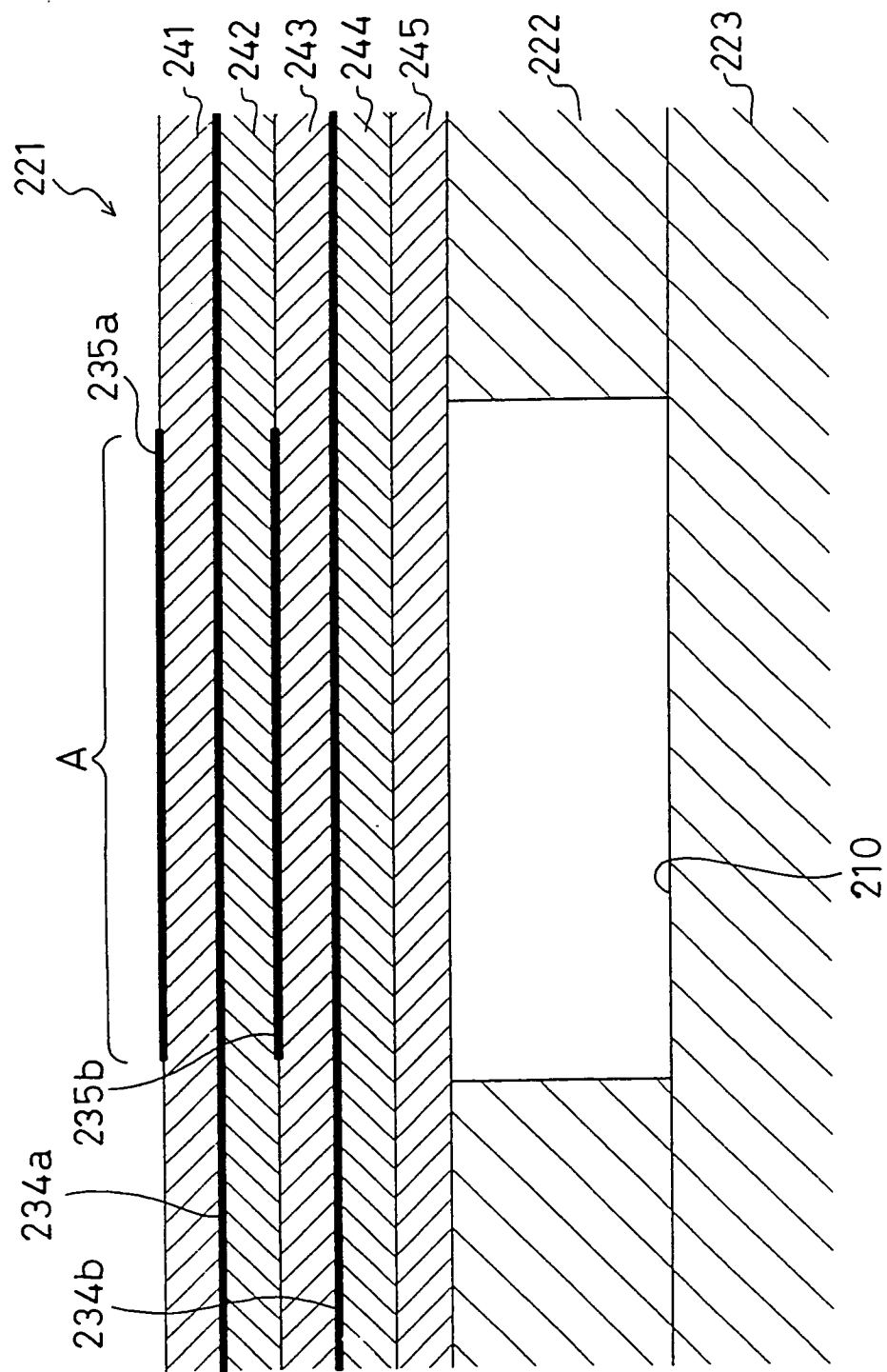


FIG. 17

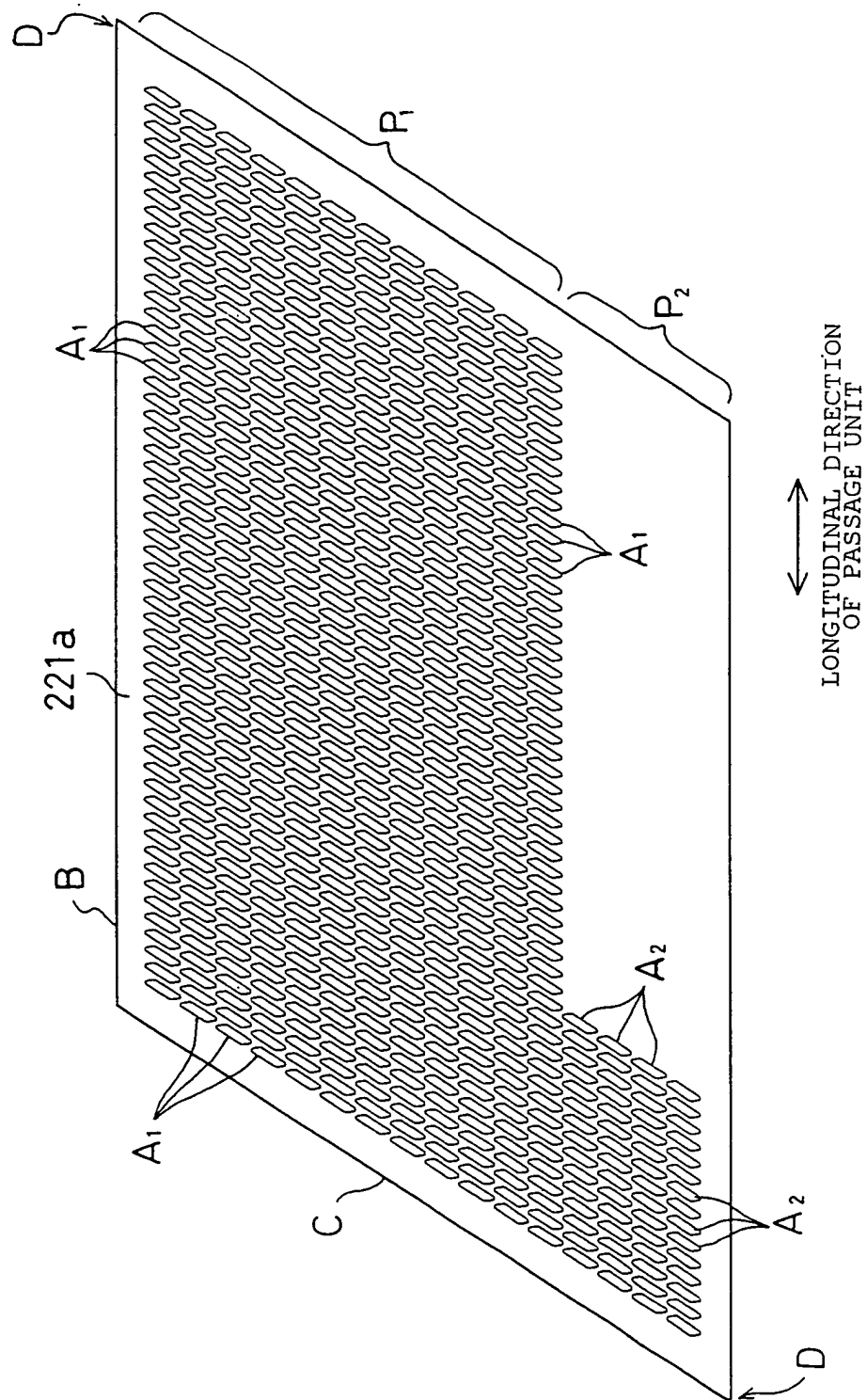


FIG. 18

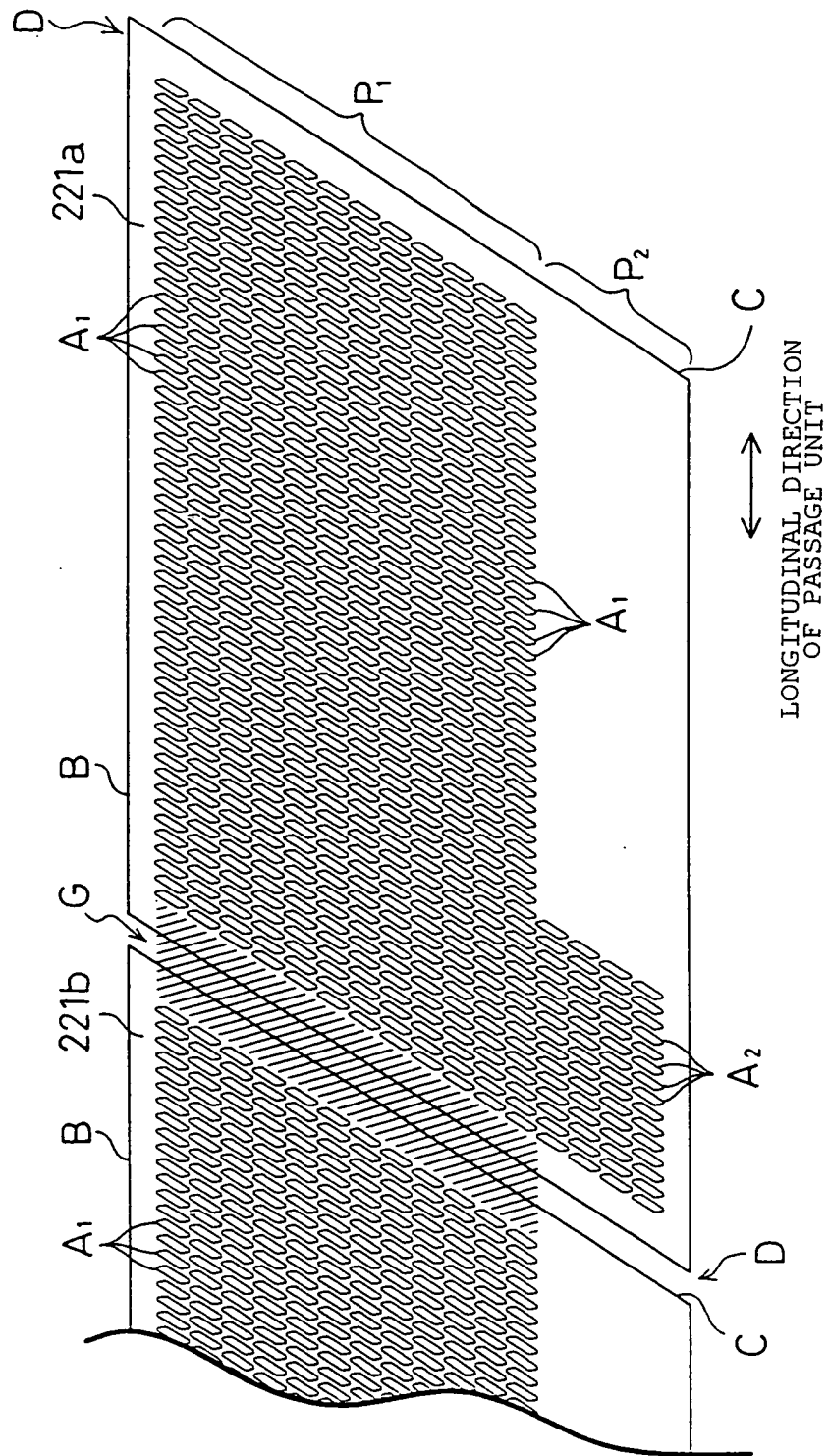


FIG. 19

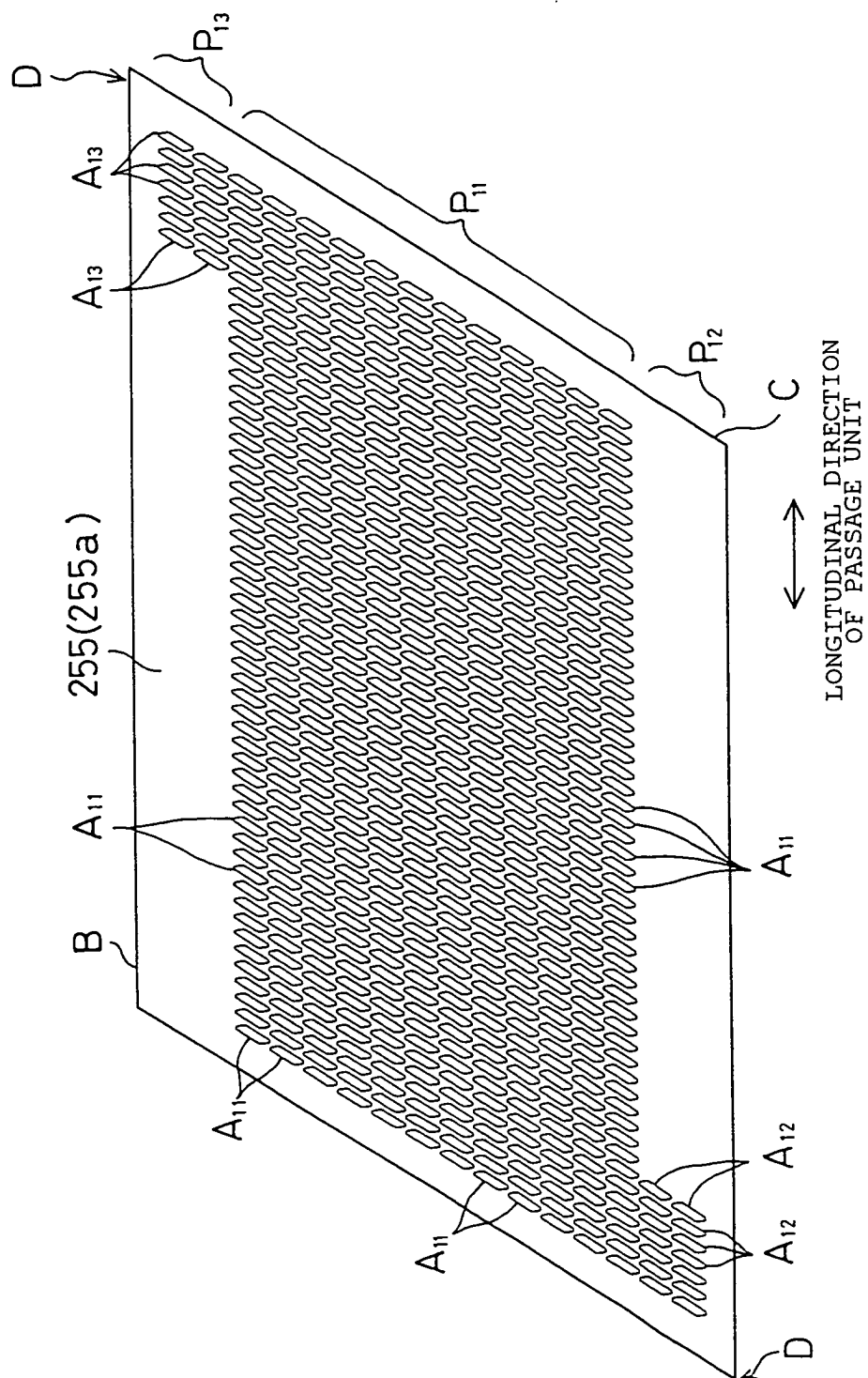


FIG. 20

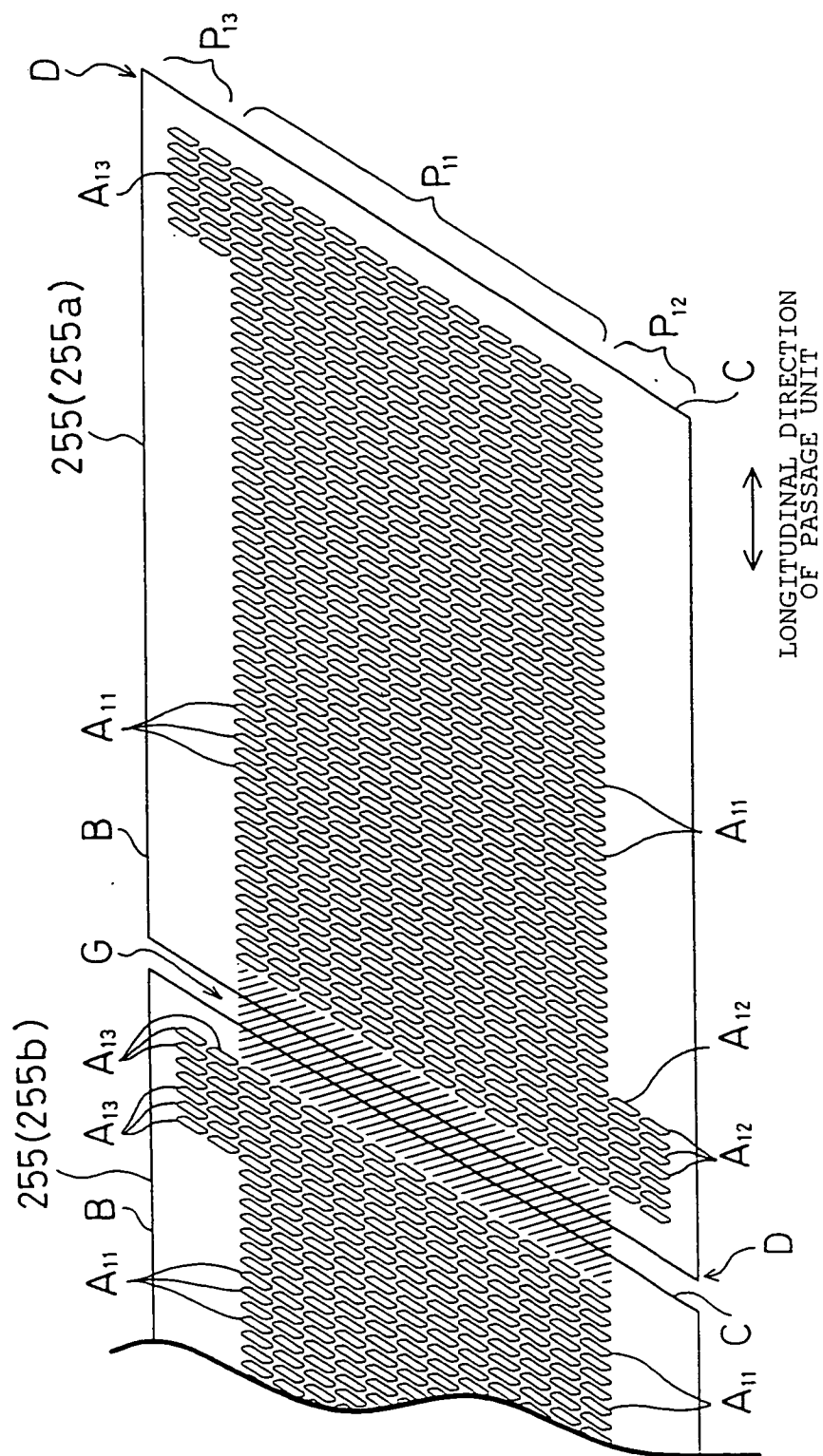


FIG. 21A

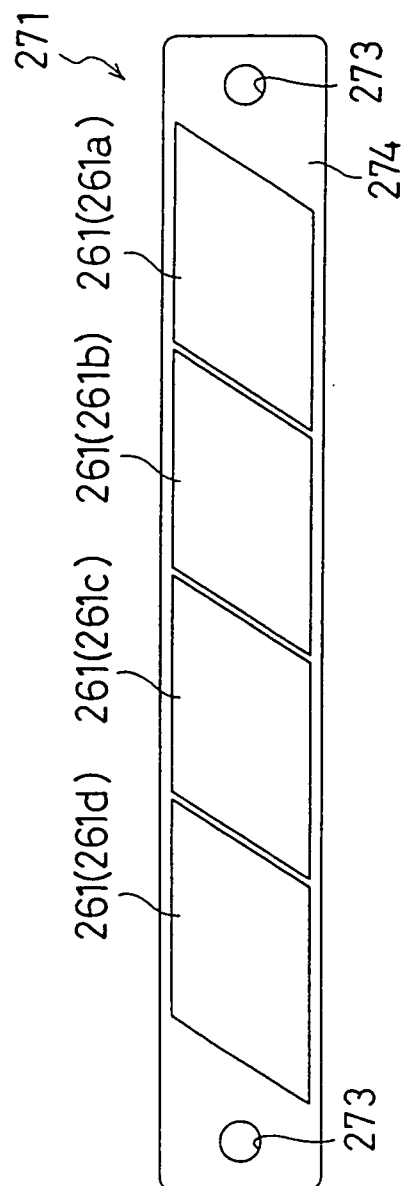


FIG. 21B

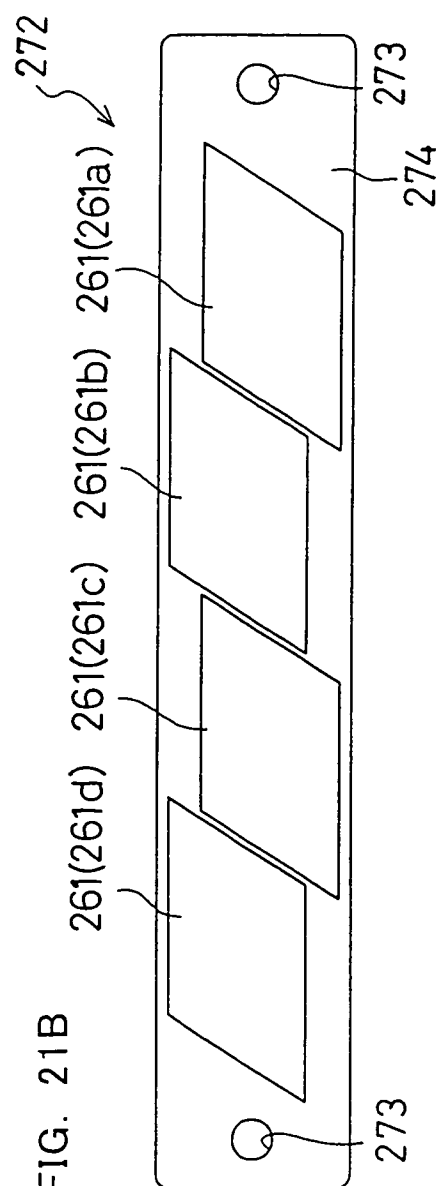


FIG. 22

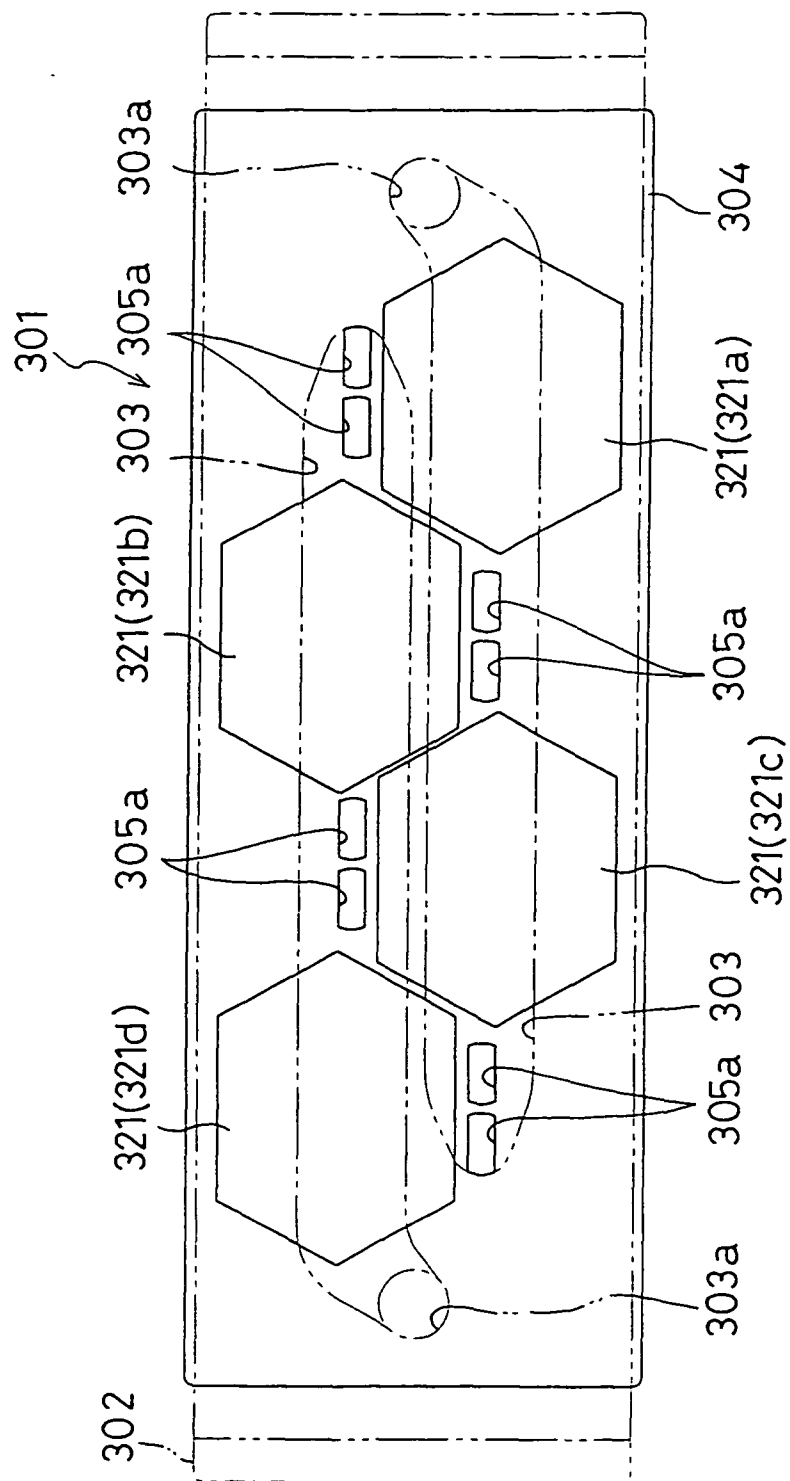


FIG. 23

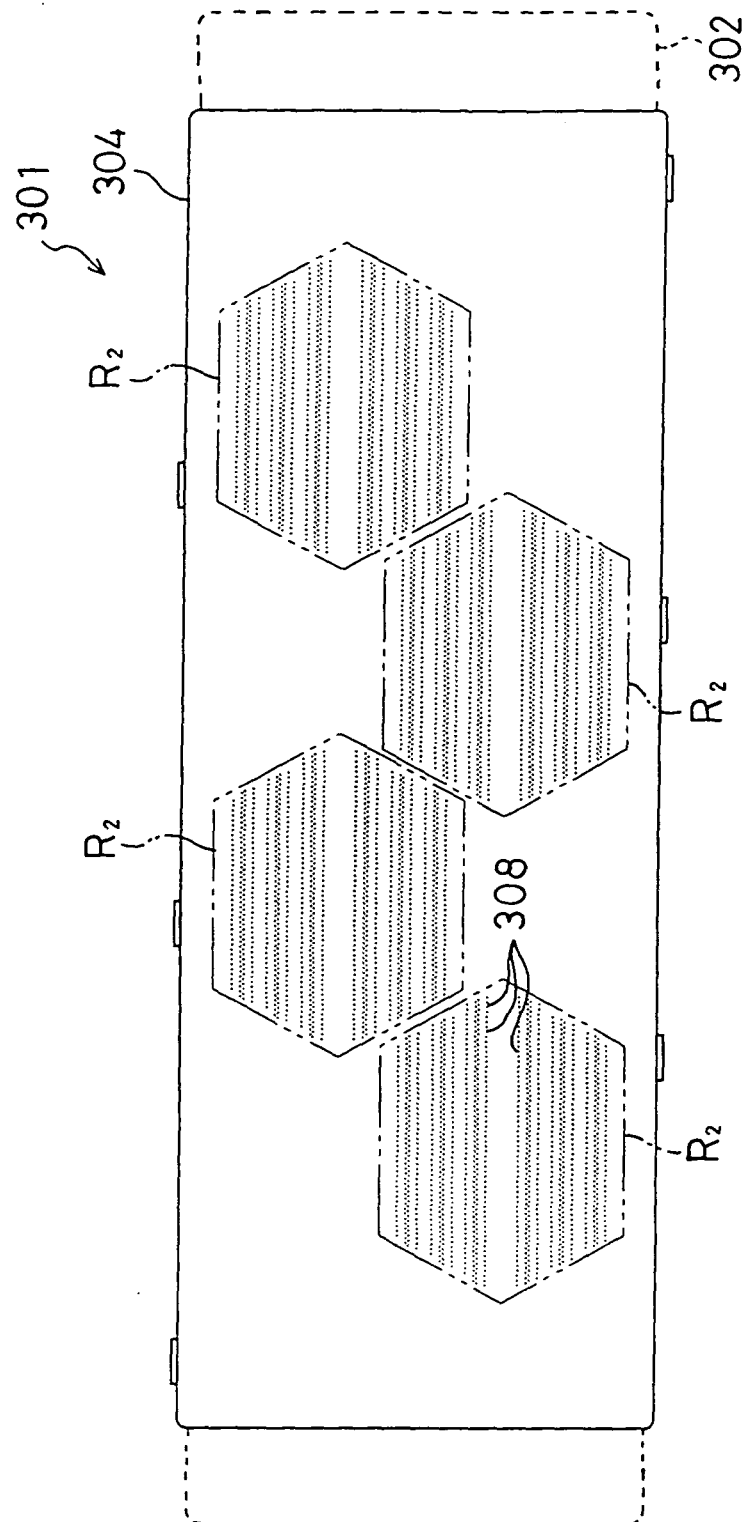


FIG. 24

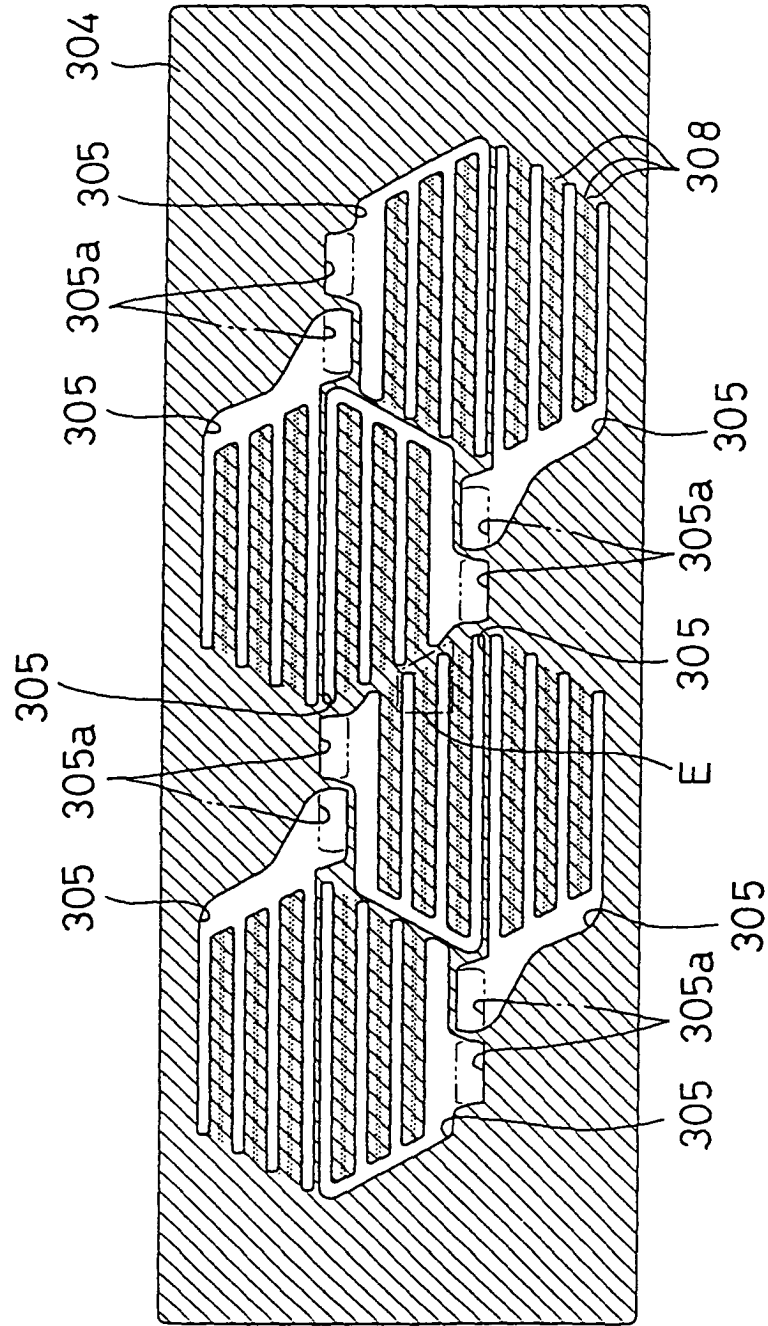


FIG. 25

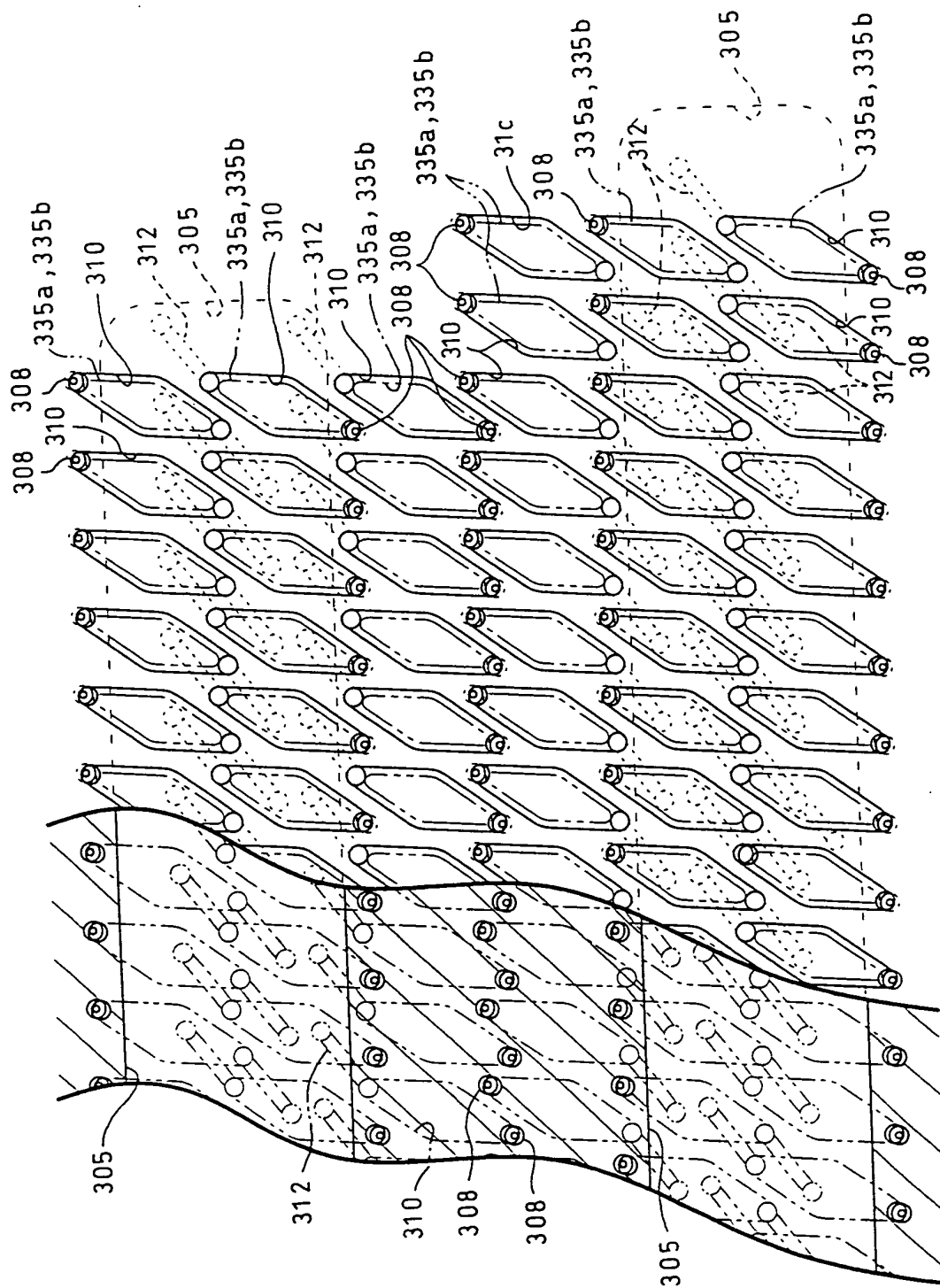


FIG. 26

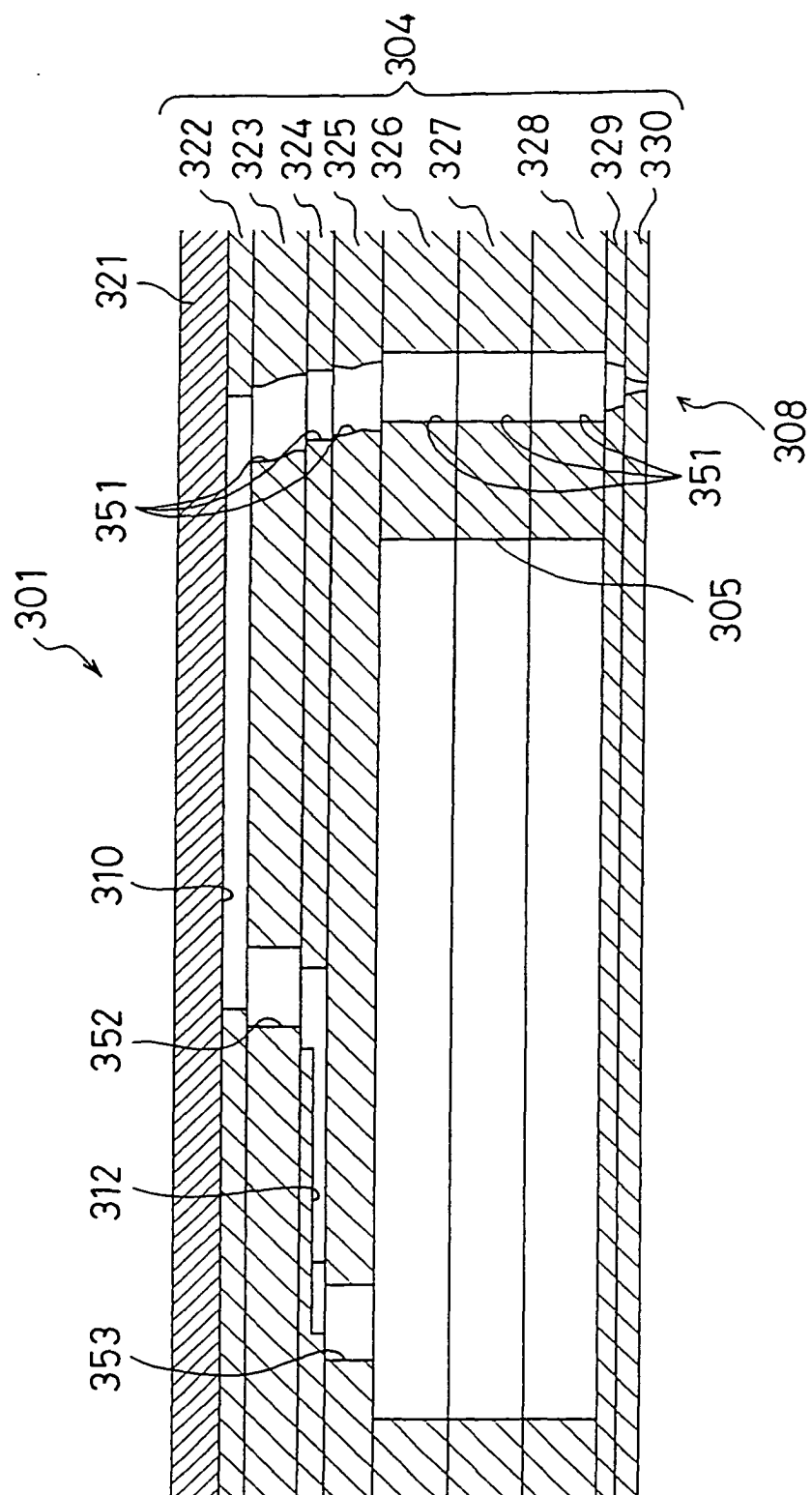


FIG. 27

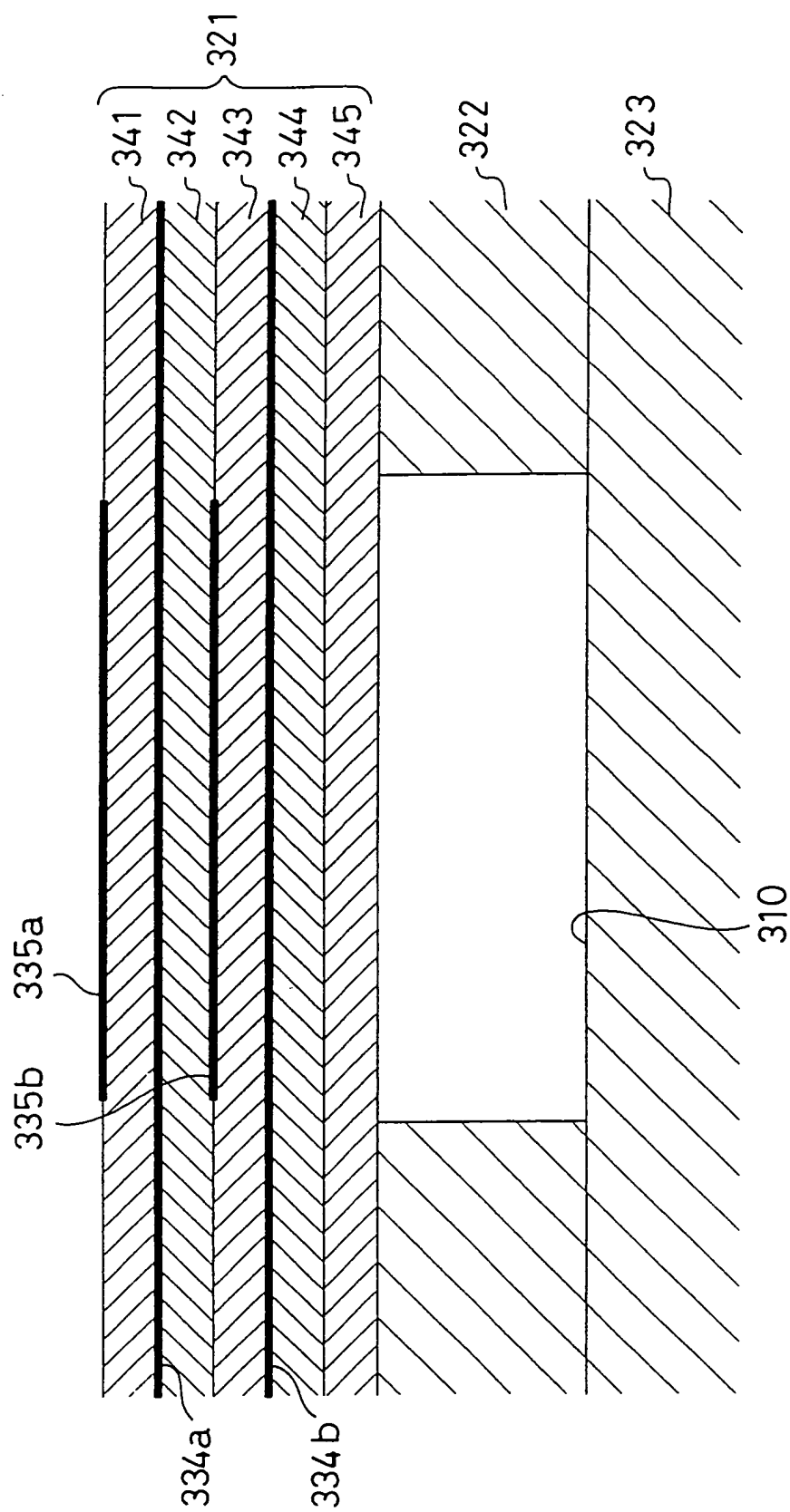


FIG. 28A

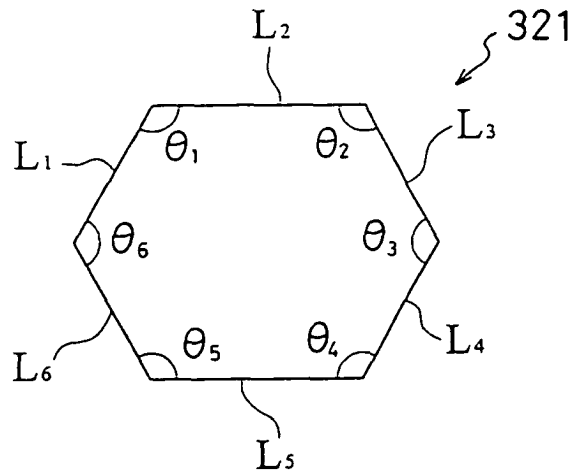
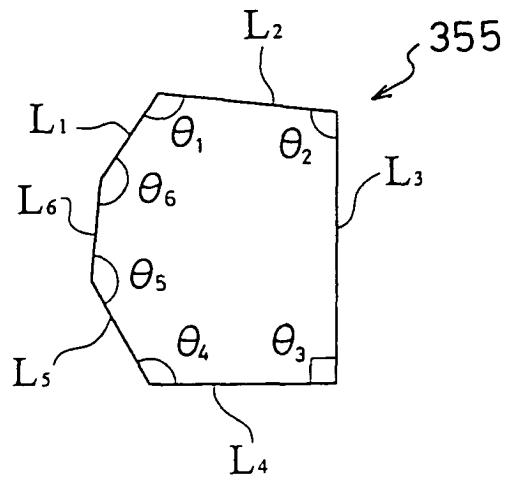


FIG. 28B



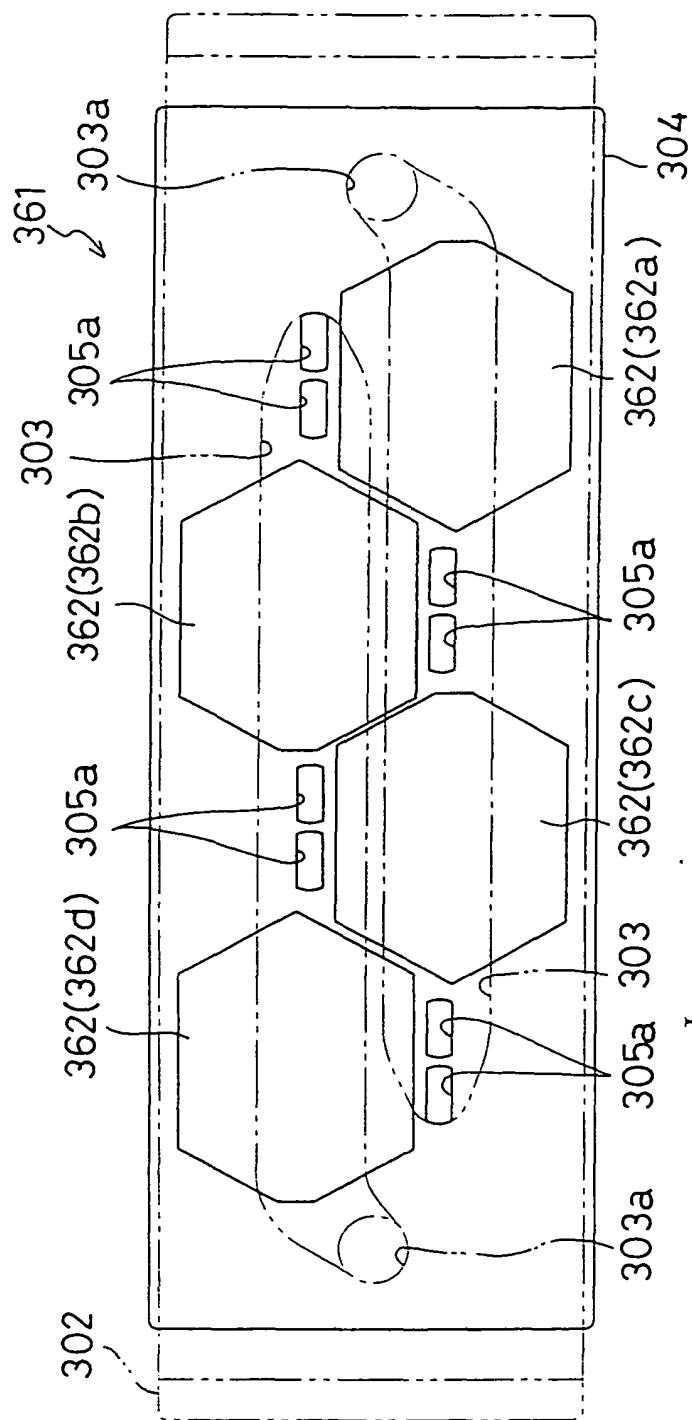


FIG. 29A

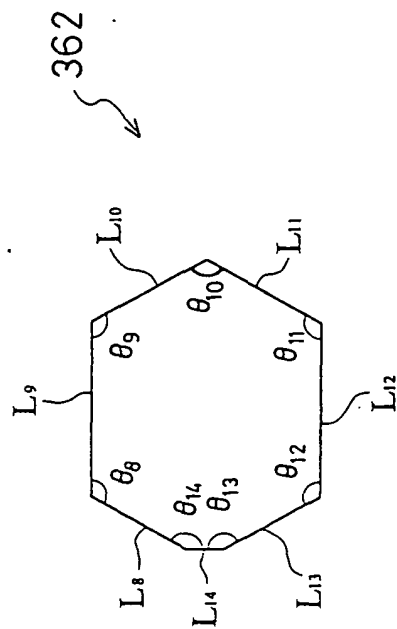


FIG. 29B

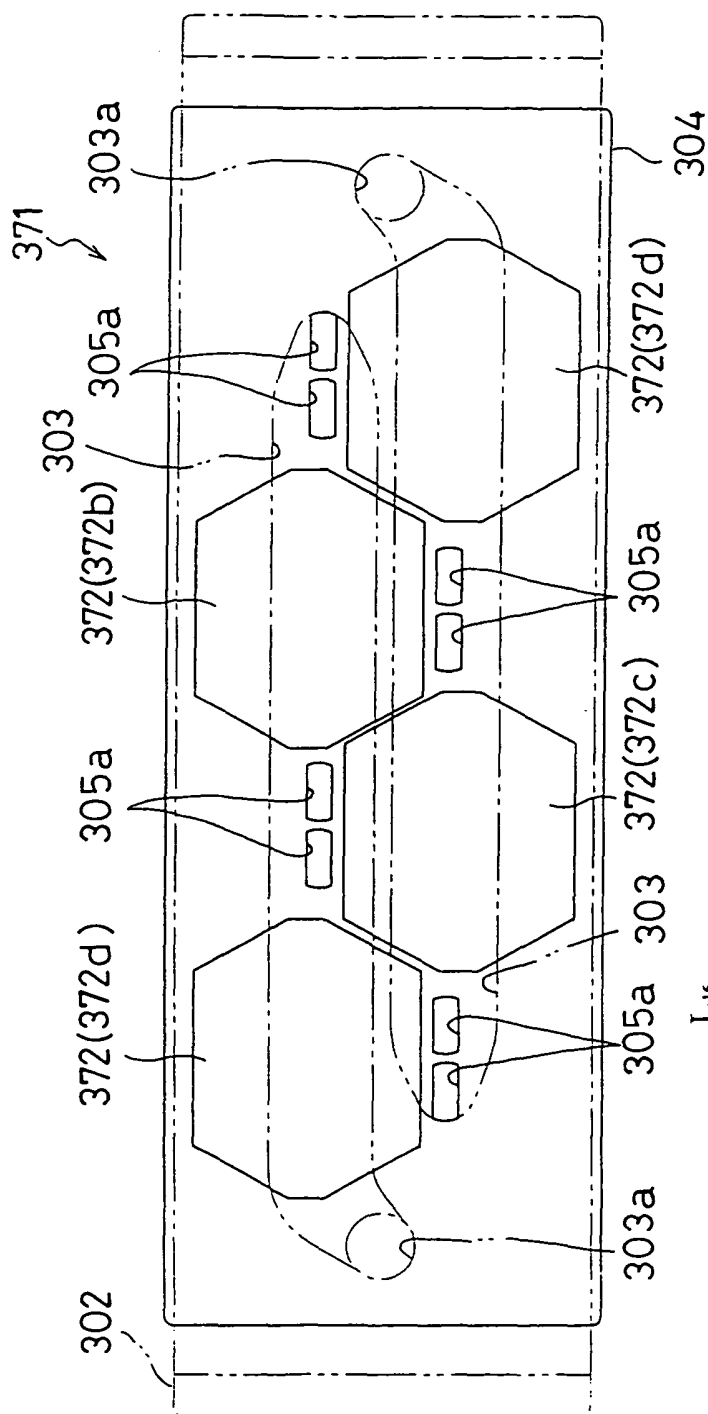


FIG. 30A

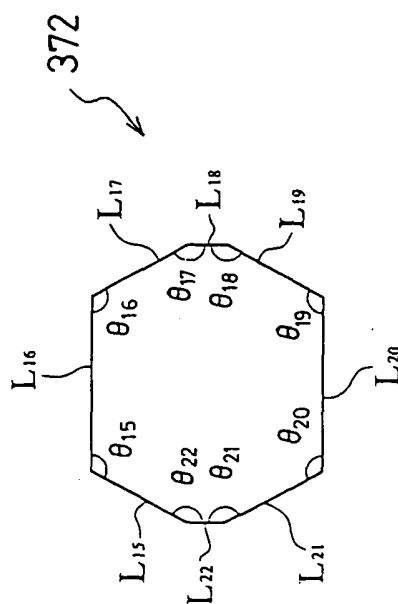


FIG. 30B

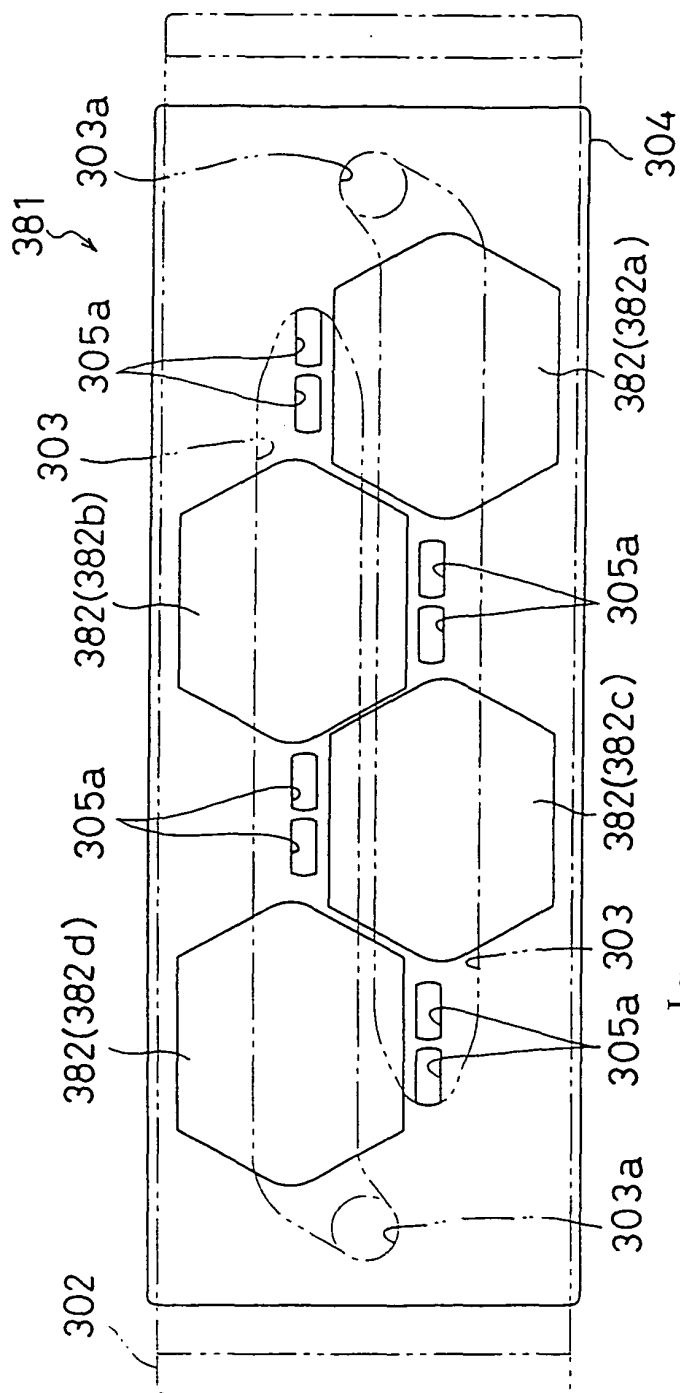


FIG. 31A

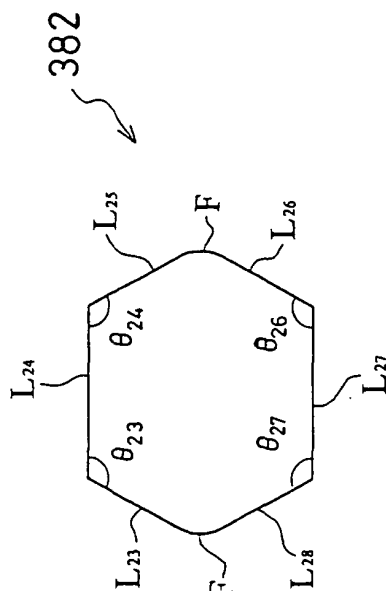


FIG. 31B

FIG. 32

