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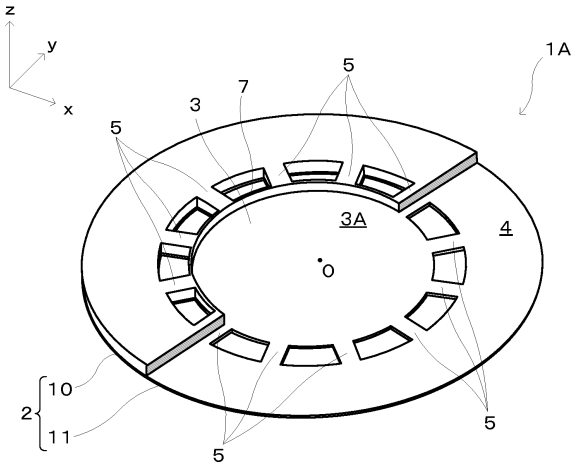
(54) SPEAKER ELEMENT AND ARRAY SPEAKER

(57) A diaphragm (3) has a plurality of connection pieces (5) disposed on an outer edge of a major surface (3A), the connection pieces (5) protruding outward along the major surface (3A) and being connected to an outer frame (4). A piezoelectric element is layered on the diaphragm (3) and becomes deformed under application of a voltage to cause the diaphragm (3) to vibrate. The thickness of the connection pieces (5) along a z-axis direction is greater than a sheet thickness of the diaphragm (3) in a region on which the piezoelectric element is layered. The connection pieces (5) protrude from the major surface (3A) in the z-axis direction.

FIG.1A



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Description

Technical Field

[0001] The present disclosure relates to a speaker element and an array speaker.

Background Art

[0002] Patent Literature 1 discloses a piezoelectric acoustic transducer that includes a piezoelectric ceramic, a circular metal plate, and a case. In the piezoelectric acoustic transducer, the piezoelectric ceramic and the metal plate are caused to vibrate in the thickness direction of the piezoelectric ceramic by expansion or contraction of the piezoelectric ceramic.

[0003] By disposing protrusions around the metal plate, the piezoelectric acoustic transducer enables the metal plate, during vibration, to transport less stress in a circumferential direction around the perimeter of the metal plate. Therefore, the resonance frequency can be shifted to a much lower side than in conventional piezoelectric acoustic transducers.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Patent No. 3123435

Summary of Invention

Technical Problem

[0005] In the above-described piezoelectric acoustic transducer, vibrations of the metal plate are regulated only at the connections between the protrusions and the case. Accordingly, as compared with cases where the entire perimeter of a metal plate is fixed, the metal plate produces less regulated vibrations and thus more freely vibrates in response to vibrations of the piezoelectric ceramic.

[0006] Thus, a standing wave pattern of vibration created in the metal plate (the vibrating body) is independent of an outer shape of the piezoelectric ceramic (the piezoelectric element) to be deformed in accordance with a voltage signal corresponding to a sound (for example, the pattern does not become similar to an outer shape of the piezoelectric ceramic). Therefore, the piezoelectric acoustic transducer poses a problem of outputting disturbed sound waves.

[0007] The present disclosure has been made in view of the foregoing circumstances, and an objective of the disclosure is to provide a speaker element and an array speaker that can reduce disturbed sound waves to achieve higher sound quality.

Solution to Problem

[0008] To achieve the above-described objective, a speaker element according to a first aspect of the present disclosure includes:

a diaphragm with a plurality of connection pieces disposed on an outer edge of a major surface of the diaphragm, the connection pieces protruding outward along the major surface and being connected to another member; and
a piezoelectric element that is layered on the diaphragm and becomes deformed under application of a voltage to cause the diaphragm to vibrate,
wherein a thickness of the connection pieces along a direction orthogonal to the major surface is greater than a sheet thickness of the diaphragm in a region on which the piezoelectric element is layered, and
wherein the connection pieces protrude from the major surface in a direction orthogonal to the major surface.

[0009] In this case, an annular wall may be formed annularly along the outer edge of the major surface of the diaphragm, the annular wall protruding from the major surface in a direction orthogonal to the major surface and being contiguous and flush with the connection pieces.

[0010] A projection may be disposed on the annular wall in a region being connected to each of the connection pieces, the projection including an inner wall that faces a center of the major surface and protrudes toward the center of the major surface.

[0011] The projection may protrude in a curved manner as seen from a direction orthogonal to the major surface.

[0012] The projection may be in a line-symmetrical shape with respect to a virtual straight line extending from the

center of the major surface of the diaphragm and dividing each of the connection pieces equally.

[0013] The connection pieces may be equally spaced along the outer edge of the major surface of the diaphragm.

[0014] The connection pieces, the number of which is at least six, may be disposed along the outer edge of the major surface of the diaphragm.

[0015] The connection pieces, the number of which is twelve, may be disposed along the outer edge of the major surface of the diaphragm.

[0016] The diaphragm and the piezoelectric element may be circular as seen from a direction orthogonal to the major surface.

[0017] An array speaker according to a second aspect of the present disclosure includes:
a plurality of the speaker elements according to the present disclosure, the speaker elements being arranged in a two-dimensional array.

[0018] In this case, the speaker elements, the number of which is four, may be adjacent to one another and may be arranged so as to be individually positioned at vertices of a square.

[0019] The speaker elements, the number of which is three, may be adjacent to one another and may be arranged so as to be individually positioned at vertices of an equilateral triangle.

[0020] The array speaker may include an outer frame that surrounds an array of the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the outer frame, and
the speaker elements may be connected by linking together the connection pieces that are not connected to the outer frame.

[0021] The array speaker may include:

an outer frame that surrounds an array of the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the outer frame; and
an auxiliary member that is disposed in a gap between the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the auxiliary member.

[0022] The array speaker may further include:
an extension that extends from an inner edge of the outer frame and is connected to the connection pieces.

[0023] The array speaker may include:
a support frame that surrounds the individual speaker elements and is connected to the connection pieces included in the speaker elements.

Advantageous Effects of Invention

[0024] According to the present disclosure, the thickness of the connection pieces connecting the diaphragm to another member is greater than the sheet thickness of the diaphragm in a region on which the piezoelectric element is layered. Hence, the connection pieces can stably support the diaphragm, and therefore, a standing wave pattern of vibration created in the diaphragm can conform to an outer shape of the piezoelectric element, which becomes deformed in accordance with a voltage signal corresponding to a sound. As a result, the diaphragm can be prevented from producing unwanted vibrations, and thus disturbed sound waves can be reduced to improve the sound quality.

Brief Description of Drawings

[0025]

FIG. 1A is a partly broken perspective view illustrating a structure of a speaker element according to Embodiment 1 of the present disclosure;
FIG. 1B is a perspective view of the speaker element in FIG. 1A, seen from an opposite direction;
FIG. 2 is a cross-sectional view taken from FIG. 1B to show a structure of the speaker element;
FIG. 3 illustrates a structure of a signal system for driving the speaker element;
FIG. 4A is an explanatory drawing (part 1) illustrating deformation of the speaker element;
FIG. 4B is an explanatory drawing (part 2) illustrating deformation of the speaker element;
FIG. 5A is a drawing (part 1) illustrating a relationship between the number of connection pieces formed on a diaphragm and a stress distribution;
FIG. 5B is a drawing (part 2) illustrating a relationship between the number of connection pieces formed on a

diaphragm and a stress distribution;
FIG. 5C is a drawing (part 3) illustrating a relationship between the number of connection pieces formed on a diaphragm and a stress distribution;
FIG. 5D is a drawing (part 4) illustrating a relationship between the number of connection pieces formed on a diaphragm and a stress distribution;
FIG. 6 is a perspective view of the speaker element with a piezoelectric element placed on the major surface;
FIG. 7 is a perspective view of the speaker element with no annular wall disposed;
FIG. 8 is a top view of a speaker element according to Embodiment 2 of the present disclosure;
FIG. 9 is an enlarged top view of a region around a projection;
FIG. 10 is an enlarged perspective view of a region around a projection;
FIG. 11 is a top view showing a variation of the projection;
FIG. 12 is a top view illustrating a configuration of an array speaker according to Embodiment 3 of the present disclosure;
FIG. 13 is a top view illustrating a configuration of an array speaker according to Embodiment 4 of the present disclosure;
FIG. 14 is a top view illustrating a configuration of an array speaker according to Embodiment 5 of the present disclosure; and
FIG. 15 is a top view illustrating a configuration of an array speaker according to Embodiment 6 of the present disclosure.

Description of Embodiments

[0026] A speaker element and an array speaker according to an embodiment of the present disclosure will now be described in detail with reference to the drawings.

Embodiment 1

[0027] As illustrated in FIGS. 1A and 1B, a speaker element 1A according to the present embodiment is formed on a substrate 2, which is a disk-shaped stack of layers each having a uniform thickness. A disk-shaped diaphragm 3 is formed in a central area including a center O of the substrate 2. The diaphragm 3 is formed to be concentric with the substrate 2.

[0028] A round surface of the diaphragm 3 on the +z side is designated as a major surface 3A, while a round surface on the -z side is designated as a back surface 3B. Since each of the layers forming the substrate 2 has a uniform thickness, the major surface 3A and the back surface 3B are parallel to each other. An outer frame 4 (a different member), which is ring-shaped and concentric with the diaphragm 3, is disposed around the diaphragm 3 to be spaced apart from the diaphragm 3.

[0029] The diaphragm 3 and the outer frame 4 are connected via twelve connection pieces 5. In other words, the connection pieces 5 each protrude outward along the major surface 3A (the back surface 3B) (protruding outward in a direction along the radius of the substrate 2 from the outer edge of the major surface 3A (the back surface 3B) and the end of each connection piece 5 connects with the outer frame 4. The connection pieces 5 are equally spaced by 30 degrees along the outer edge of the major surface 3A and the back surface 3B of the diaphragm 3.

[0030] The outer frame 4 is fixed to a fixing member (not illustrated). The diaphragm 3 has flexibility to be able to vibrate while being supported by the outer frame 4 via the connection pieces 5. In this way, the diaphragm 3 is supported by a plurality of the equally spaced connection pieces 5. As a result, when compared with cases where the diaphragm 3 is supported all along its perimeter, the diaphragm 3 is more stably supported, the diaphragm 3 vibrates at a greater amplitude, and the resonance frequency of the diaphragm 3 can be set to a lower value.

[0031] As illustrated in FIG. 1B, a piezoelectric element 6 is layered on a central area of the back surface 3B of the diaphragm 3. When a voltage is applied, the piezoelectric element 6 becomes deformed in accordance with the voltage to cause the diaphragm 3 to vibrate. Vibrations of the diaphragm 3 make a sound. In the present embodiment, the diaphragm 3 with the disposed connection pieces 5 and the piezoelectric element 6 form the speaker element 1A. The piezoelectric element 6 is circular as seen from a direction (the z-axis direction) orthogonal to the major surface 3A and the back surface 3B of the diaphragm 3 and is concentric with the substrate 2 and the diaphragm 3.

[0032] In practice, the substrate 2 is made of a silicon-on-insulator (SOI) substrate. The SOI substrate is a wafer containing an oxide film, that is, a semiconductor substrate having a laminated structure made of a BOX layer constituting a buried oxide film and a silicon (SOI) layer constituting a semiconductor layer on the BOX layer. The BOX layer is formed of a silicon oxide film (SiO_2) and has a thickness of, for example, several micrometers. An SOI substrate is used for manufacturing semiconductors made of layers each having a uniform thickness.

[0033] As illustrated in FIG. 2, the substrate 2 is formed by layering an Si support layer 10, which includes a base

wafer and the BOX layer. An Si active layer 11, which is an element wafer active layer, is layered on the Si support layer 10. The Si active layer 11 is formed of silicon (Si) and has a thickness of, for example, 150 μm.

[0034] As seen in FIG. 1A, in the present embodiment, the diaphragm 3 is made of the Si active layer 11, while the outer frame 4 and the connection pieces 5 are made of the Si support layer 10 and the Si active layer 11. Hence, the connection piece 5 protrudes in the +z direction from the major surface 3A of the diaphragm 3, and the thickness of the connection piece 5 along the z-axis direction of the diaphragm 3 is greater than the sheet thickness of the diagram 3 in a region on which the piezoelectric element 6 is layered. As a result, the connection pieces 5 can more stably support the diaphragm 3. In addition, the connection piece 5 is as thick as the outer frame 4 and is contiguous and flush with the outer frame 4. As a result, local stress to be created is reduced and the connection pieces 5 are less likely to be damaged.

[0035] In the present embodiment, an annular wall 7, which is a wall shaped like a ring, is formed along the outer edge of the major surface 3A of the diaphragm 3. The annular wall 7 protrudes in the +z direction from the major surface 3A of the diaphragm 3 and is contiguous and flush with the connection pieces 5. Since the annular wall 7 is contiguous with the connection pieces 5 supporting the diaphragm 3, a relative positional relationship between connection pieces 5 varies to a minimum extent, and the connection pieces 5 can more stably support the diaphragm 3.

[0036] The piezoelectric element 6, or specifically a first electrode layer 12, a piezoelectric element layer 13, and a second electrode layer 14 are layered on the Si active layer 11. The first electrode layer 12 is formed of an electrically conductive member such as platinum or gold, and has a thickness of 1 μm or less. The piezoelectric element layer 13 is formed of a piezoelectric material to expand and contract under the application of a voltage, and has a thickness of several micrometers. Examples of an employed material for the piezoelectric body include lead zirconate titanate (Pb (Zr, Ti) O_3: PZT). The second electrode layer 14 is formed of an electrically conductive member such as platinum or gold, and has a thickness of 1 μm or less.

[0037] A signal system is connected to the speaker element 1A for supplying a voltage signal corresponding to a sound to be produced. As illustrated in FIG. 3, the signal system includes a sound signal output device 20 and a signal modulator 21.

[0038] The sound signal output device 20 outputs a voltage signal corresponding to a sound to be reproduced by the speaker element 1A. The frequency of the voltage signal falls within an audible range.

[0039] The signal modulator 21 modulates a voltage signal output by the sound signal output device 20 with a predetermined modulation frequency. Examples of an employed predetermined modulation frequency include a frequency around 40 kHz. Examples of an employed modulation method for the signal modulator 21 include amplitude modulation (AM).

[0040] The voltage signal modulated by the signal modulator 21 is applied to the piezoelectric element 6 to be a voltage signal between the second electrode layer 14 and the first electrode layer 12. This voltage signal causes the piezoelectric element 6 to vibrate and a sound wave is generated.

[0041] For example, as shown in FIG. 4A, when a positive voltage is applied to the second electrode layer 14 and a negative voltage is applied to the first electrode layer 12, the piezoelectric element layer 13 expands in the xy directions indicated by arrows. However, the Si active layer 11 does not expand, with the result that the piezoelectric element 6 is curved to project in the -z direction.

[0042] In contrast, as shown in FIG. 4B, when a negative voltage is applied to the second electrode layer 14 and a positive voltage is applied to the first electrode layer 12, the piezoelectric element layer 13 contracts in the xy directions indicated by arrows. However, the Si active layer 11 does not contract, with the result that the piezoelectric element 6 is curved to project in the +z direction.

[0043] Note that, in response to an applied voltage, the piezoelectric element layer 13 may expand or contract conversely to what is described above, depending on the polarity of piezoelectric element layer 13. If this is the case, the piezoelectric element layer 13 is curved in the directions opposite to those indicated in FIGS. 4A and 4B.

[0044] The foregoing voltage signal oscillates between positive and negative voltages. Thus, in response to such voltage signals, the piezoelectric element layer 13 alternates between the states illustrated in FIGS. 4A and 4B to vibrate. Such vibration generates a sound wave traveling in the +z direction.

[0045] The speaker element 1A according to the present embodiment provides a greater vibration displacement of the diaphragm 3 because the diaphragm 3 is supported via the connection pieces 5. Hence, the electromechanical coupling coefficient measured when the diaphragm 3 is caused to vibrate with a voltage applied to the piezoelectric element 6 can be increased.

[0046] In addition, in the speaker element 1A, the thickness of the connection pieces 5 connecting the diaphragm 3 to the outer frame 4 is greater than the sheet thickness of the diaphragm 3 in a region on which the piezoelectric element 6 is layered. Hence, the connection pieces 5 themselves are prevented from deforming and can stably support the diaphragm 3, and therefore, a standing wave pattern of vibration created in the diaphragm 3 can conform to an outer shape of the piezoelectric element 6, which becomes deformed in accordance with a voltage signal corresponding to a sound (for example, the pattern can be similar to an outer shape of the piezoelectric element 6). As a result, when

compared with a speaker element in which the diaphragm 3 is supported all along its perimeter (a speaker element having no opening between the diaphragm 3 and the outer frame 4), the frequency can be set to a lower band, and furthermore, the diaphragm 3 is prevented from producing unwanted vibrations, and thus disturbed sound waves can be reduced to improve the sound quality.

[0047] The number of the connection pieces 5 is twelve in the present embodiment. However, the number may not always be twelve in the present disclosure. For example, the number of the connection pieces 5 may be three to ten as shown in FIGS. 5A, 5B, 5C, and 5D; provided that the connection pieces 5 are equally spaced along the circumference of the diaphragm 3.

[0048] FIGS. 5A to 5D each show a stress distribution generated on the diaphragm 3. FIG. 5A shows that, when the number of the connection pieces 5 is three (spaced by 120 degrees), the stress distribution differs between radial directions. Likewise, FIG. 5B shows that, when the number of the connection pieces 5 is four (spaced by 90 degrees), the stress distribution differs between radial directions.

[0049] By contrast, FIG. 5C shows that, when the number of the connection pieces 5 is six (spaced by 60 degrees), the stress varies uniformly without regard to radial directions. The same applies to FIG. 5D, which shows ten connection pieces 5 (spaced by 36 degrees). Thus, the stress with respect to a direction along a radius of the diaphragm 3 varies more uniformly as the number of the connection pieces 5 increases.

[0050] When the number of the connection pieces 5 is at least six, the stress with respect to radial directions varies uniformly without regard to radial directions. Hence, desirably at least six connection pieces 5 are disposed along the outer edge of the major surface 3A of the diaphragm 3.

[0051] In the present embodiment, the piezoelectric element 6 is disposed on the back surface 3B, but this is not restrictive in the present disclosure. For example, the piezoelectric element 6 may be disposed on the major surface 3A as illustrated in FIG. 6. For this configuration, the speaker element may be manufactured by, for example, using micro-electromechanical systems (MEMS) technology, which is a semiconductor manufacturing technology for micro-machining, to produce the speaker element 1A except the piezoelectric element 6, namely the diaphragm 3, the outer frame 4, the connection pieces 5, and the annular wall 7, and then bonding the piezoelectric element 6, which is made of, for example, a ceramic, onto the back surface 3B of the diaphragm 3 that has been produced.

[0052] As shown in FIG. 7, the annular wall 7 may not necessarily be disposed. In this case, the connection pieces 5 are still capable of stably supporting the diaphragm 3 because the connection pieces 5 are formed to be thicker than other portions of the diaphragm 3.

Embodiment 2

[0053] The following describes Embodiment 2 of the present disclosure.

[0054] As shown in FIG. 8, a speaker element 1B according to the present embodiment is the same as the speaker element 1A according to Embodiment 1 above except that the annular wall 7 is different in shape from the annular wall in the foregoing embodiment. The annular wall 7 in the speaker element 1B includes a projection 7A disposed in a region connected to the connection piece 5.

[0055] The projection 7A is disposed such that the inner wall facing the center O of the major surface 3A of the diaphragm 3 protrudes toward the center of the major surface 3A. Specifically, as illustrated in FIG. 9, the projection 7A protrudes in a curved manner as seen from the z-axis direction. In other words, the length from the inner wall of the projection 7A to the center O continuously varies.

[0056] Further specifically, the projection 7A is in a line-symmetrical shape with respect to a virtual straight line A extending from the center O of the major surface 3A of the diaphragm 3 and dividing the connection piece 5 equally. The projection 7A starts protruding at a position distant from the virtual straight line A by L2 and reaches a maximum protrusion whose length is L1 on the virtual straight line A. In other words, the projection 7A has the shortest length from its inner wall to the center O at a position where the length of the protrusion is represented by L1.

[0057] Assuming that there is no projection 7A, a greater stress would be caused on regions B1 and B2 (see FIG. 10) than on other regions of the diaphragm 3, the regions B1 and B2 corresponding to a joint between the inner wall of the annular wall 7 where the connection piece 5 is formed and the diaphragm 3. Disposing the projection 7A on the annular wall 7 can reduce the stress caused on the regions B1 and B2.

[0058] The shape of the projection 7A is not limited to the one illustrated in FIG. 9. For example, as illustrated in FIG. 11, a portion of the projection 7A raised from the inner wall as seen from the z-axis direction may be partly cut off (for example, the raised portion may be partly straight). The projection 7A may be in any shape as long as a stress locally caused on the diaphragm 3, such as the stress caused on the regions B1 and B2, can be reduced.

[0059] According to the present embodiment, the projection 7A can reduce a stress locally caused on the diaphragm 3. As a result, the diaphragm 3 can produce stable vibrations, and a sound corresponding to a voltage signal given to the piezoelectric element 6 can be reproduced with greater fidelity. Furthermore, the diaphragm 3 is protected from damage that may be caused by a locally created stress.

Embodiment 3

[0060] The following describes Embodiment 3 of the present disclosure.

[0061] In Embodiments 1 and 2 above, configurations of single speaker elements 1A and 1B have been described. An array speaker 100A, which is described in the present embodiment, includes a plurality of the speaker elements 1A arranged in a two-dimensional array as illustrated in FIG. 12.

[0062] The array speaker 100A as a whole is disk-shaped, and an annular outer frame 4 is disposed on the outermost circumference thereof. The outer frame 4 is fixed to a fixing member (not illustrated). The plurality of the speaker elements 1A is arranged in an area surrounded by an inner circumferential wall of the outer frame 4. The plurality of the speaker elements 1A is arranged such that sounds are produced in the same +z direction.

[0063] The speaker elements 1A are arranged such that every three speaker elements 1A adjacent to one another are positioned at vertices of an equilateral triangle. The outer frame 4 supports the speaker elements 1A by being connected to those connection pieces 5 which are included in the speaker elements 1A and which face the outer frame 4. The connection pieces 5 included in each speaker element 1A are used to connect adjacent speaker elements 1A. In this way, the speaker elements 1A are structured to support one another.

[0064] Since twelve connection pieces 5 are spaced by 30 degrees around each speaker element 1A, the connection pieces 5 are at the same positions between any adjacent speaker elements 1A when the speaker elements 1A are positioned at vertices of an equilateral triangle. Therefore, the speaker elements 1A can be easily connected by linking together those connection pieces 5 which are at the same positions.

[0065] In order that the outer frame 4 is uniformly spaced apart from the speaker elements 1A, arc-shaped extensions 4A connected to the connection pieces 5 are disposed on the inner edge of the outer frame 4. As a result, the lengths of the connection pieces 5 are kept as uniform as possible, and the supported speaker elements 1A remain well-balanced.

[0066] According to the present embodiment, the speaker elements 1A are directly connected to each other, and thus the plurality of the speaker elements 1A to produce sounds in the same +z direction can be closely arranged, whereby higher directivity is achieved.

[0067] The number of the arranged speaker elements 1A is six in the present embodiment, but the number is not limited to six in the present disclosure. The number of the speaker elements 1A may be less than six, or may be seven or more. In place of the speaker elements 1A, the speaker elements 1B (see FIG. 8) may be arranged.

Embodiment 4

[0068] The following describes Embodiment 4 of the present disclosure.

[0069] An array speaker 100B according to the present embodiment also includes a plurality of the speaker elements 1A arranged in a two-dimensional array as illustrated in FIG. 13. While the array speaker 100A according to Embodiment 3 above includes the speaker elements 1A arranged such that adjacent speaker elements 1A are positioned at vertices of an equilateral triangle, the array speaker 100B includes four speaker elements 1A, which are adjacent to one another and are arranged to be positioned at vertices of a square.

[0070] The array speaker 100B as a whole is square-shaped, and an annular outer frame 4 is disposed on the outermost perimeter with the inner wall of the outer frame 4 including semicircular portions each protruding toward the speaker elements 1A. The outer frame 4 is fixed to a fixing member (not illustrated). The plurality of the speaker elements 1A is arranged in an area surrounded by the inner wall of the outer frame 4.

[0071] The outer frame 4 supports the speaker elements 1A by being connected to those connection pieces 5 which are included in the speaker elements 1A and which face the outer frame 4. A circular auxiliary member 8 is placed among the speaker elements 1A adjacent to one another. The auxiliary member 8 supports the speaker elements 1A by being connected to those connection pieces 5 which are included in the speaker elements 1A and which face the auxiliary member 8. The speaker elements 1A in the array speaker 100B can be more stably supported because the connection pieces 5 are connected not only to the outer frame 4 fixed to a fixing member but also to the auxiliary member 8 fixed to a fixing member. Note that the auxiliary member 8 may not necessarily be fixed to a fixing member.

[0072] In order that the outer frame 4 is uniformly spaced from the speaker elements 1A, extensions 4A each being connected to the connection pieces 5, being semicircular or quadrant-like, and being an equivalent of the auxiliary member 8, are disposed on the inner edge of the outer frame 4. As a result, the lengths of the connection pieces 5 are kept as uniform as possible, and the supported speaker elements 1A remain well-balanced.

[0073] Since twelve connection pieces 5 are spaced by 30 degrees around each speaker element 1A as described above, the connection pieces 5 are at the same positions between any adjacent speaker elements 1A when the speaker elements 1A are positioned at vertices of a square. Therefore, the speaker elements 1A can be easily connected by linking together those connection pieces 5 which are at the same positions.

[0074] The plurality of the speaker elements 1A is arranged such that sounds are produced in the same +z direction, which makes the array speaker 100B an array speaker having a high directivity. Furthermore, the speaker elements 1A

producing sounds in the same direction are directly connected to each other so as to be closely arranged, whereby higher directivity is achieved.

[0075] The number of the arranged speaker elements 1A is four in the present embodiment, but the number is not limited to four in the present disclosure. The number of the speaker elements 1A may be less than four, or may be five or more. In place of the speaker elements 1A, the speaker elements 1B may be arranged.

Embodiment 5

[0076] The following describes Embodiment 5 of the present disclosure.

[0077] In the array speaker 100A according to Embodiment 3 above, the connection pieces 5 included in each speaker element 1A are used to connect adjacent speaker elements 1A, as illustrated in FIG. 14. In the array speaker 100C according to the present embodiment, triangular auxiliary members 8 are used to connect the connection pieces 5 included in the speaker elements 1A adjacent to each other.

[0078] As with the outer frame 4, the auxiliary members 8 are fixed to a fixing member (not illustrated). The auxiliary members 8, each of which is placed in a gap between the speaker elements 1A, support the speaker elements 1A by being connected to those connection pieces 5 which are included in the speaker elements 1A and which face the auxiliary members 8. The speaker elements 1A in the array speaker 100C can be more stably supported because the connection pieces 5 are connected not only to the outer frame 4 fixed to a fixing member but also to the auxiliary members 8 fixed to a fixing member. Note that the auxiliary members 8 may not necessarily be fixed to a fixing member.

[0079] In order that the outer frame 4 is uniformly spaced apart from the speaker elements 1A, arc-shaped extensions 4A connected to the connection pieces 5 are disposed on the inner edge of the outer frame 4. As a result, the lengths of the connection pieces 5 are kept as uniform as possible, and the supported speaker elements 1A remain well-balanced.

Embodiment 6

[0080] The following describes Embodiment 6 of the present disclosure.

[0081] As illustrated in FIG. 15, the array speaker 100D according to Embodiment 6 includes four speaker elements 1A adjacent to one another, the speaker elements 1A being arranged to be positioned at vertices of a square. The array speaker 100D further includes a support frame 9. The support frame 9 surrounds the individual speaker elements 1A and is connected to the connection pieces 5 included in the speaker elements 1A.

[0082] The support frame 9 is fixed to a fixing member (not illustrated). In addition, the support frame 9 is placed between the speaker elements 1A, and thus connected to all the connection pieces 5 included in the speaker elements 1A to support the speaker elements 1A. Since all the connection pieces 5 are supported by the support frame 9 included in the array speaker 100D, the speaker elements 1A can be more stably supported.

[0083] The diaphragm 3 is disk-shaped in the foregoing embodiments, but this is not restrictive in the present disclosure. For example, the diaphragm 3 may be like an oval plate or may be in a rectangular or any other polygonal shape.

[0084] Materials and sizes of the speaker elements 1A and 1B and the array speakers 100A to 100D are provided as examples only and are not restrictive. The sizes may be adjusted, as appropriate, depending on the specific apparatus on which the speaker device is mounted.

[0085] In the foregoing embodiments, PZT is used as the piezoelectric material, but another piezoelectric material may be used. Any other piezoelectric material, such as $BaTiO_3$ or $PbTiO_3$, or a piezoelectric single crystal, such as quartz or lithium niobate, may be used. A piezoelectric polymer film, such as zinc oxide (ZnO), vinylidene fluoride, or trifluoroethylene polymers, may also be used.

[0086] Amplitude modulation (AM) is used as a modulation method in the foregoing embodiments, but frequency modulation (FM) may also be used.

[0087] The foregoing describes some example embodiments for explanatory purposes. Although the foregoing discussion has presented specific embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the broader spirit and scope of the invention. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. This detailed description, therefore, is not to be taken in a limiting sense, and the scope of the invention is defined only by the included claims, along with the full range of equivalents to which such claims are entitled.

[0088] This application claims the benefit of Japanese Patent Application No. 2017-79686, filed on April 13, 2017, the entire disclosure of which is incorporated by reference herein.

Industrial Applicability

[0089] The present disclosure can be applied to a speaker which is attached to any of a variety of electrical apparatuses including portable devices such as smart phones, and which is needed to reproduce sounds with high directivity.

Reference Signs List

[0090]

1A, 1B	Speaker element
2	Substrate
3	Diaphragm
3A	Major surface
3B	Back surface
4	Outer frame
4A	Extension
5	Connection piece
6	Piezoelectric element
7	Annular wall
7A	Projection
8	Auxiliary member
9	Support frame
10	Si support layer
11	Si active layer
12	First electrode layer
13	Piezoelectric element layer
14	Second electrode layer
20	Sound signal output device
21	Signal modulator
100A, 100B, 100C 100D	Array speaker

Claims

1. A speaker element comprising:

a diaphragm with a plurality of connection pieces disposed on an outer edge of a major surface of the diaphragm, the connection pieces protruding outward along the major surface and being connected to another member; and
a piezoelectric element that is layered on the diaphragm and becomes deformed under application of a voltage to cause the diaphragm to vibrate,
wherein a thickness of the connection pieces along a direction orthogonal to the major surface is greater than a sheet thickness of the diaphragm in a region on which the piezoelectric element is layered, and
wherein the connection pieces protrude from the major surface in a direction orthogonal to the major surface.

2. The speaker element according to claim 1,
wherein an annular wall is formed annularly along the outer edge of the major surface of the diaphragm, the annular wall protruding from the major surface in a direction orthogonal to the major surface and being contiguous and flush with the connection pieces.

3. The speaker element according to claim 2,
wherein a projection is disposed on the annular wall in a region being connected to each of the connection pieces, the projection comprising an inner wall that faces a center of the major surface and protrudes toward the center of the major surface.

4. The speaker element according to claim 3,
wherein the projection protrudes in a curved manner as seen from a direction orthogonal to the major surface.

5. The speaker element according to claim 4,
wherein the projection is in a line-symmetrical shape with respect to a virtual straight line extending from the center of the major surface of the diaphragm and dividing each of the connection pieces equally.

6. The speaker element according to any one of claims 1 to 5,
wherein the connection pieces are equally spaced along the outer edge of the major surface of the diaphragm.

7. The speaker element according to claim 6,
wherein the connection pieces, the number of which is at least six, are disposed along the outer edge of the major surface of the diaphragm.

8. The speaker element according to claim 7,
wherein the connection pieces, the number of which is twelve, are disposed along the outer edge of the major surface of the diaphragm.

9. The speaker element according to any one of claims 1 to 8,
wherein the diaphragm and the piezoelectric element are circular as seen from a direction orthogonal to the major surface.

10. An array speaker comprising:
a plurality of the speaker elements according to any one of claims 1 to 9, the speaker elements being arranged in a two-dimensional array.

11. The array speaker according to claim 10,
wherein the speaker elements, the number of which is four, are adjacent to one another and are arranged so as to be individually positioned at vertices of a square.

12. The array speaker according to claim 10,
wherein the speaker elements, the number of which is three, are adjacent to one another and are arranged so as to be individually positioned at vertices of an equilateral triangle.

13. The array speaker according to any one of claims 10 to 12, comprising:

an outer frame that surrounds an array of the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the outer frame,
wherein the speaker elements are connected by linking together the connection pieces that are not connected to the outer frame.

14. The array speaker according to any one of claims 10 to 12, comprising:

an outer frame that surrounds an array of the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the outer frame; and
an auxiliary member that is disposed in a gap between the speaker elements and supports the speaker elements by being connected to the connection pieces which are included in the speaker elements and which connection pieces face the auxiliary member.

15. The array speaker according to claim 13 or 14, further comprising:
an extension that extends from an inner edge of the outer frame and is connected to the connection pieces.

16. The array speaker according to any one of claims 10 to 12, comprising:
a support frame that surrounds the individual speaker elements and is connected to the connection pieces included in the speaker elements.

FIG.1A

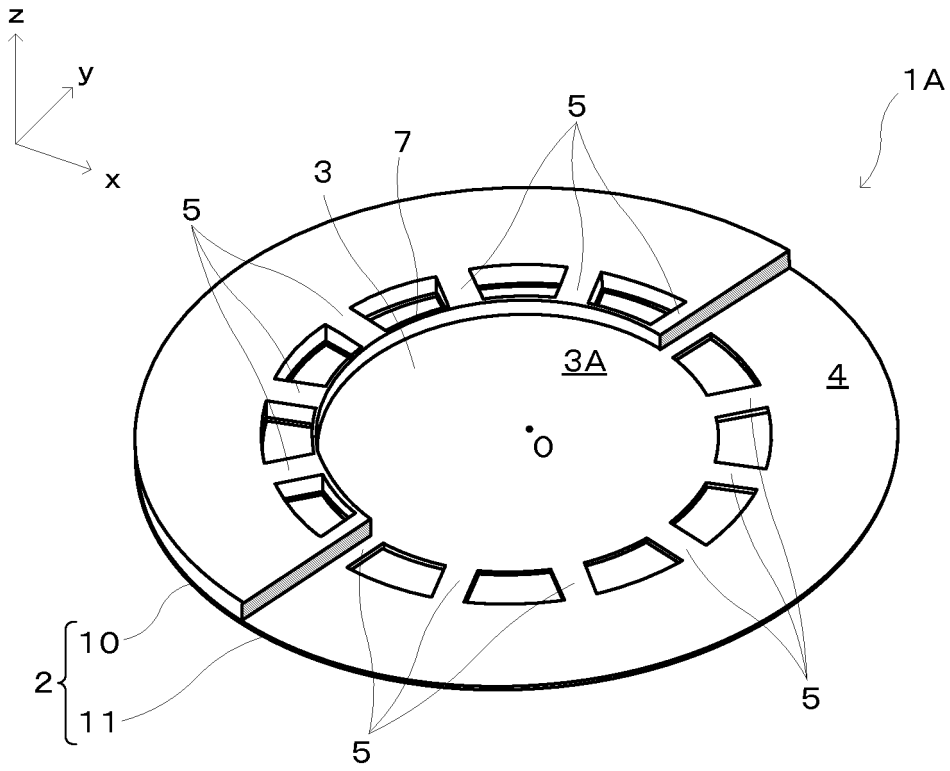


FIG.1B

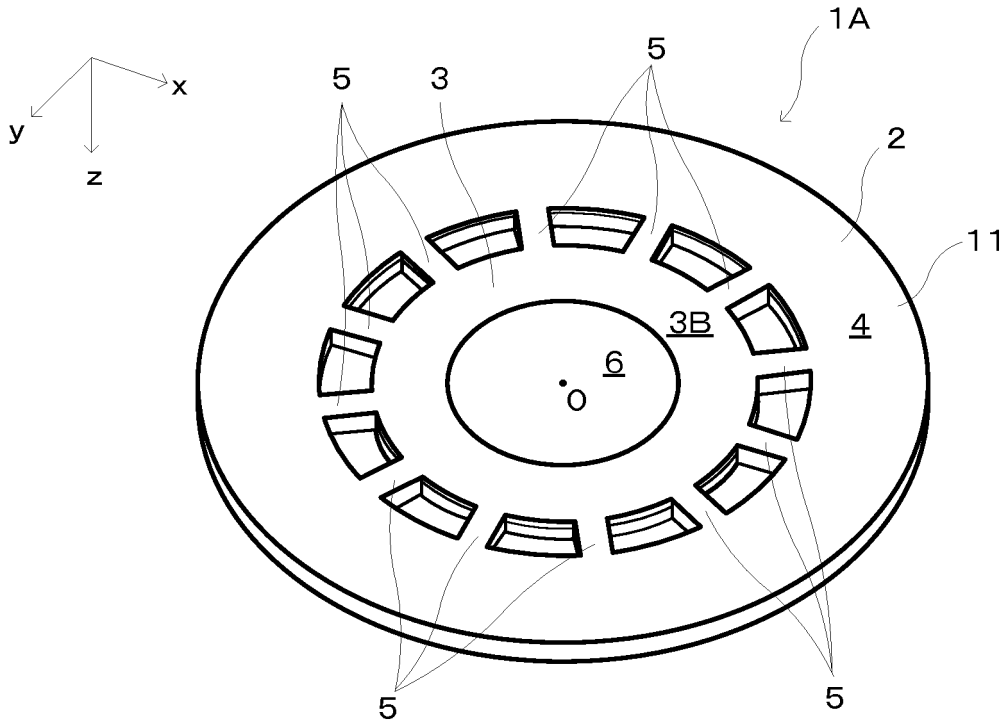


FIG.2

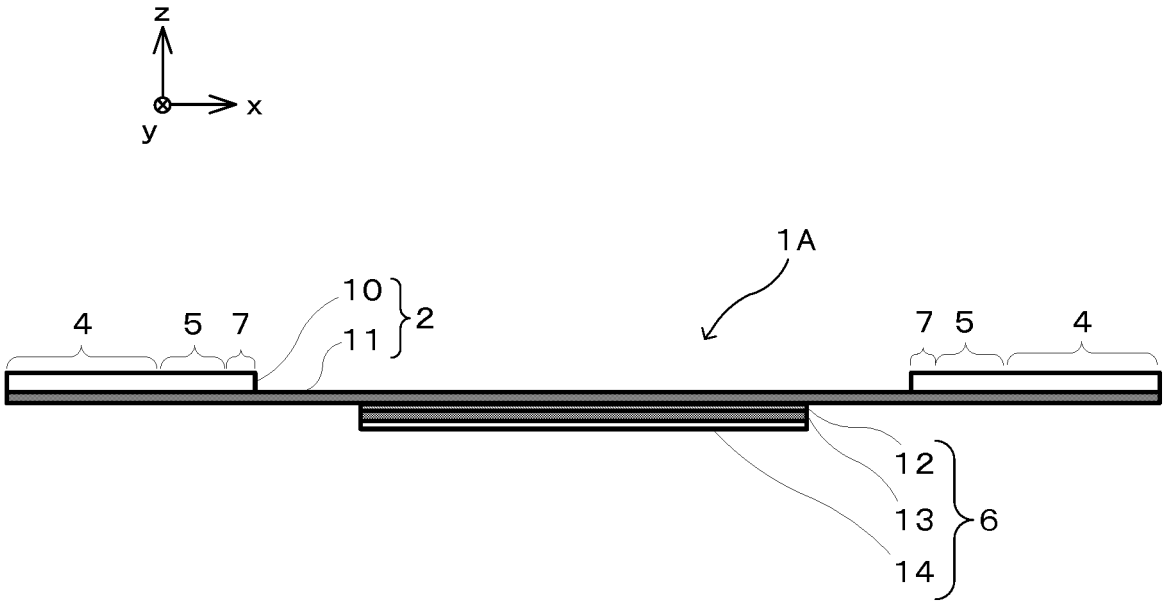


FIG.3

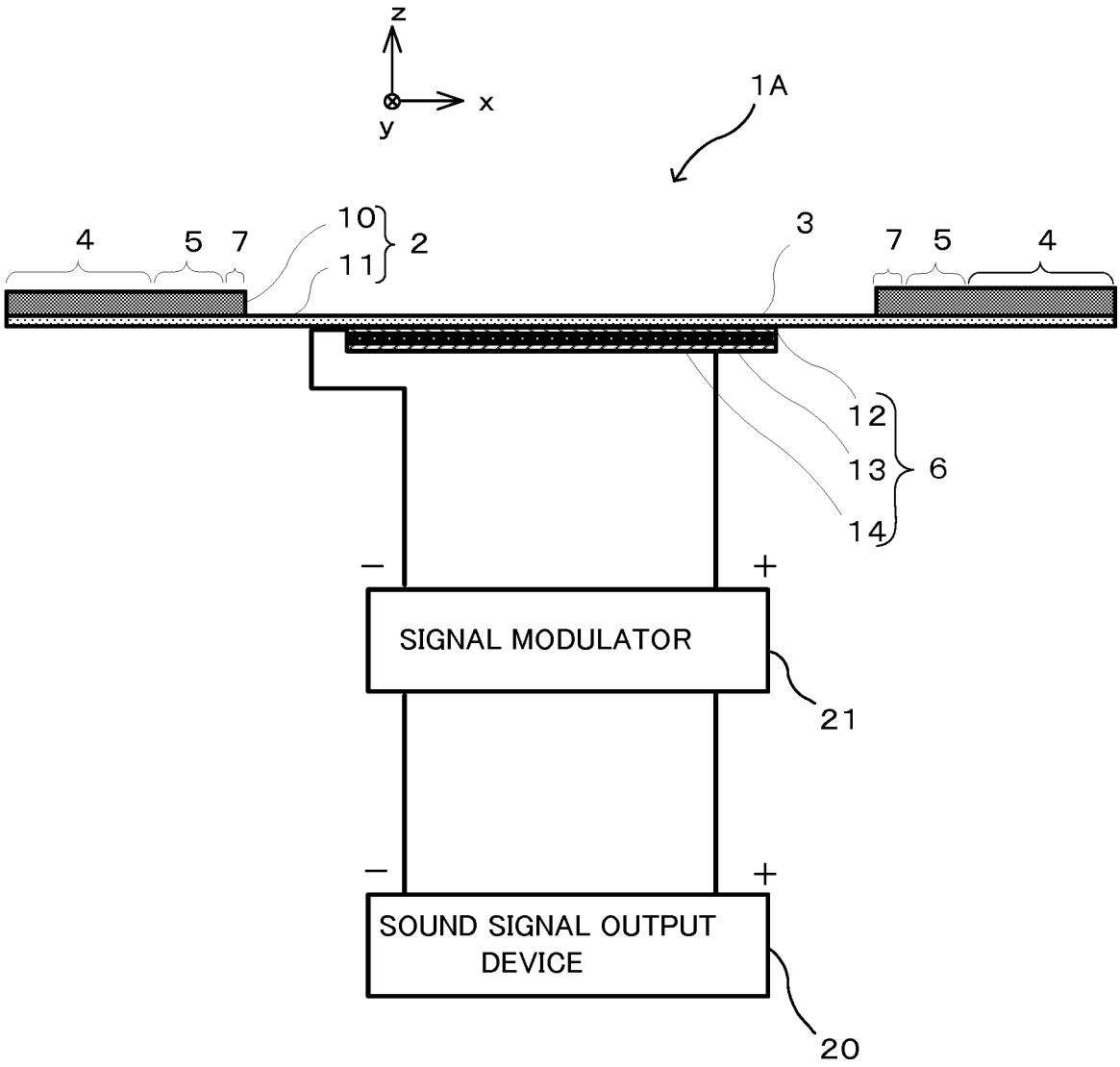

z
x
y
1A
4
5
7
10
11
2
3
7
5
4
12
13
14
6
−
+
SIGNAL MODULATOR
21
−
+
SOUND SIGNAL OUTPUT DEVICE
20

FIG.4A

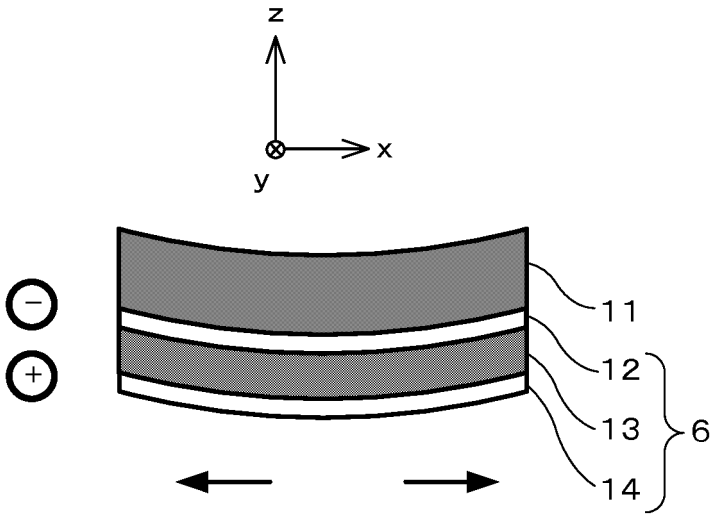


FIG.4B

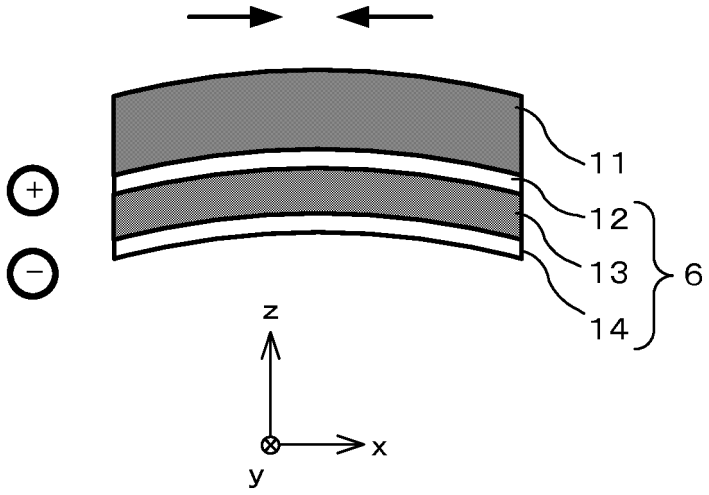


FIG.5A

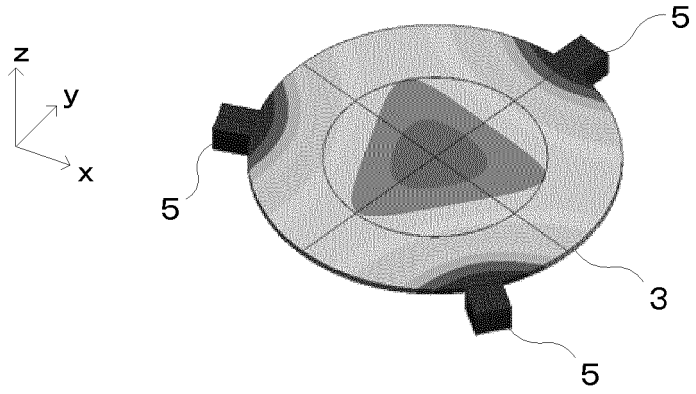


FIG.5B

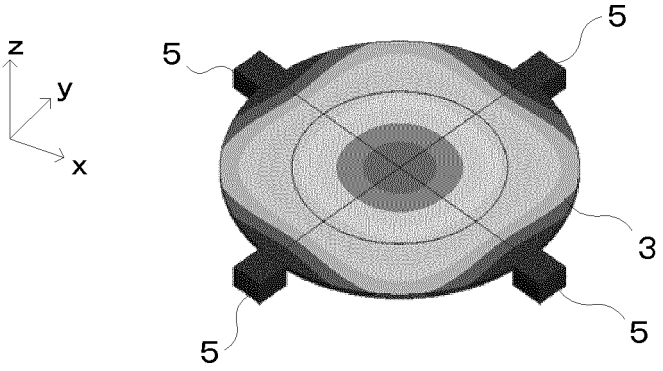


FIG.5C

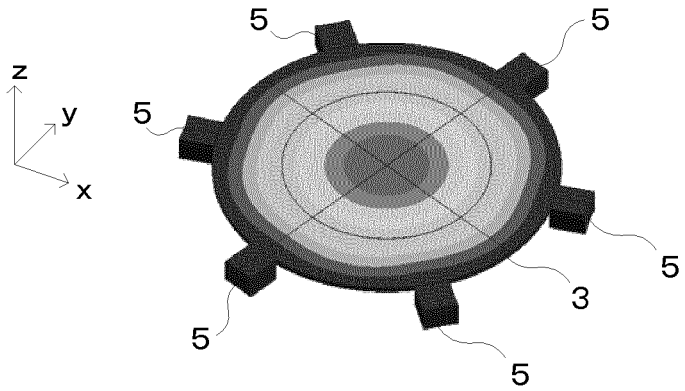


FIG.5D

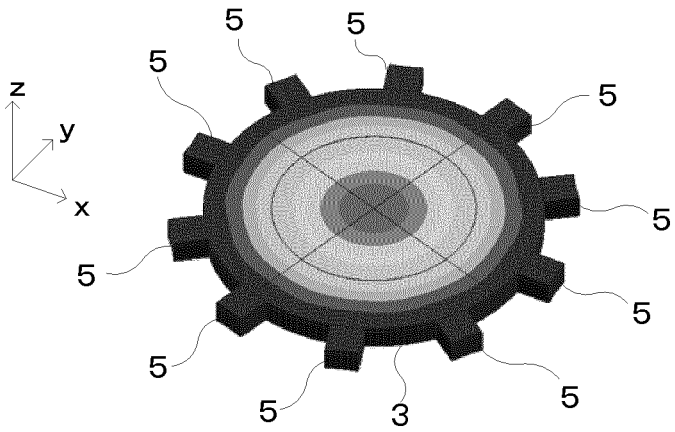


FIG.6

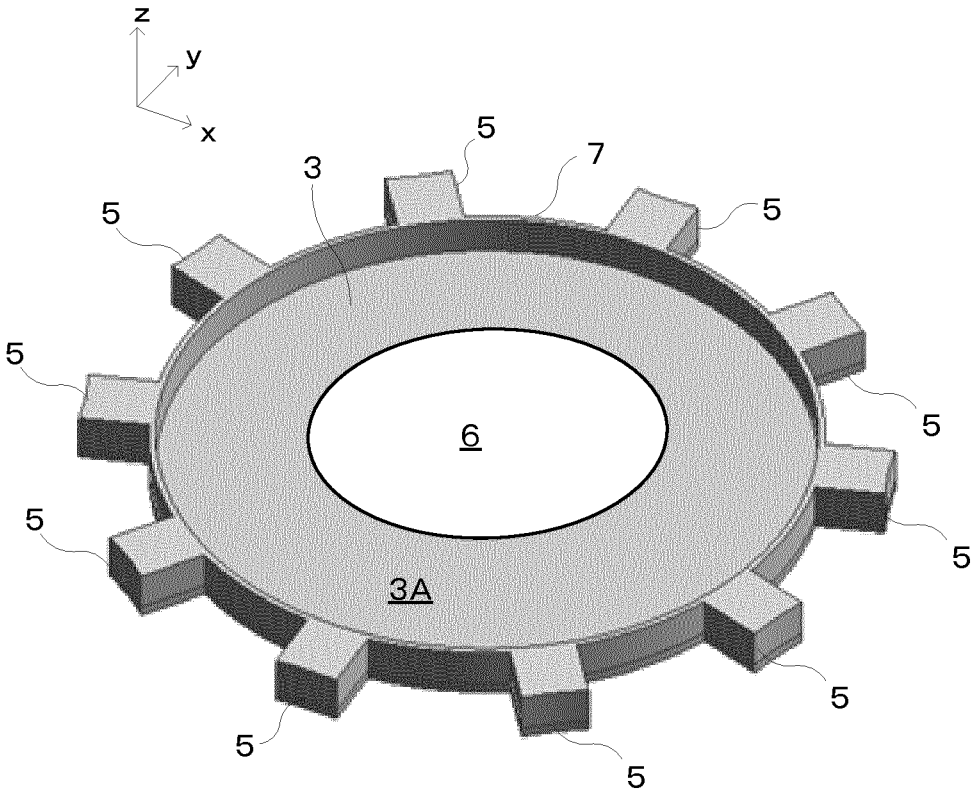


FIG.7

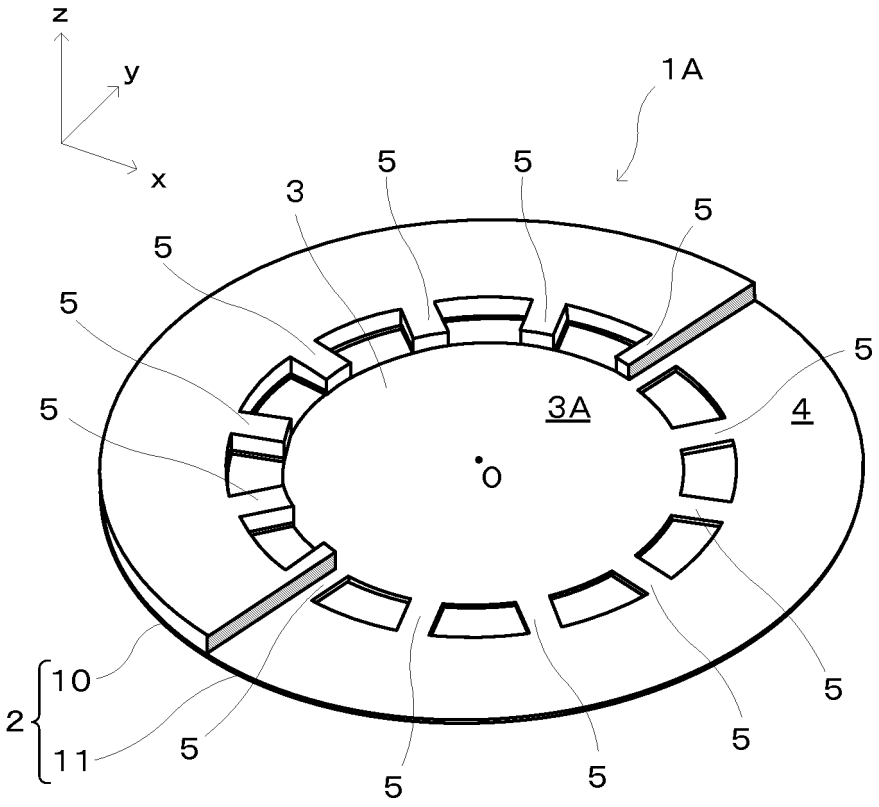


FIG.8

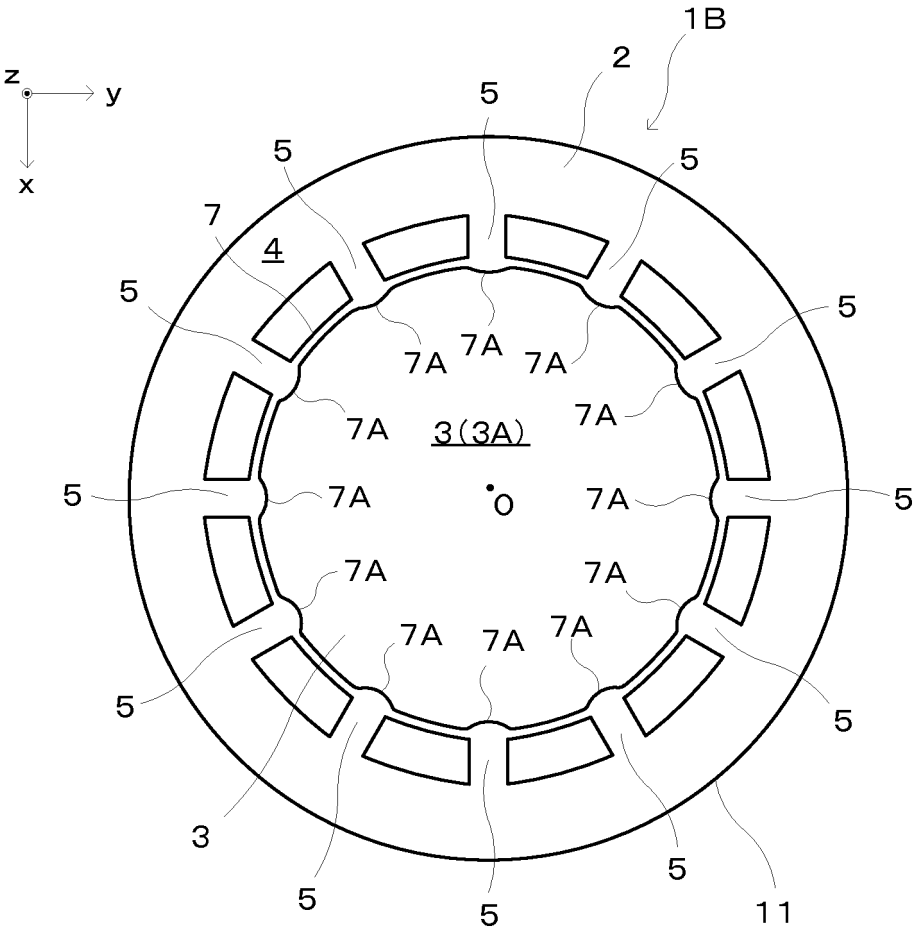


FIG.9

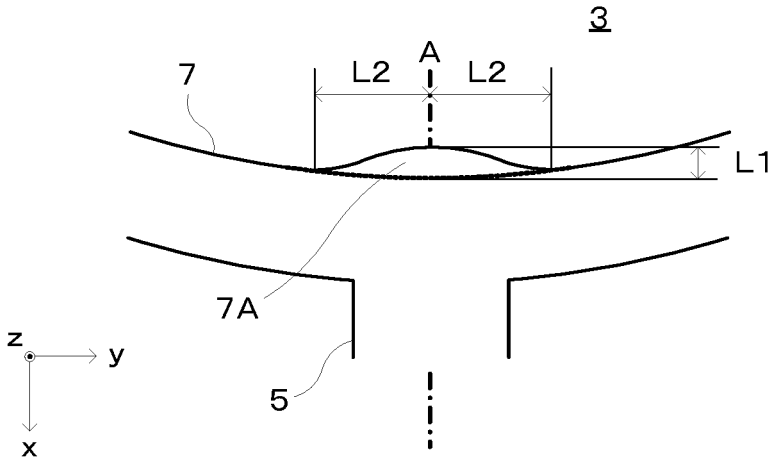


FIG.10

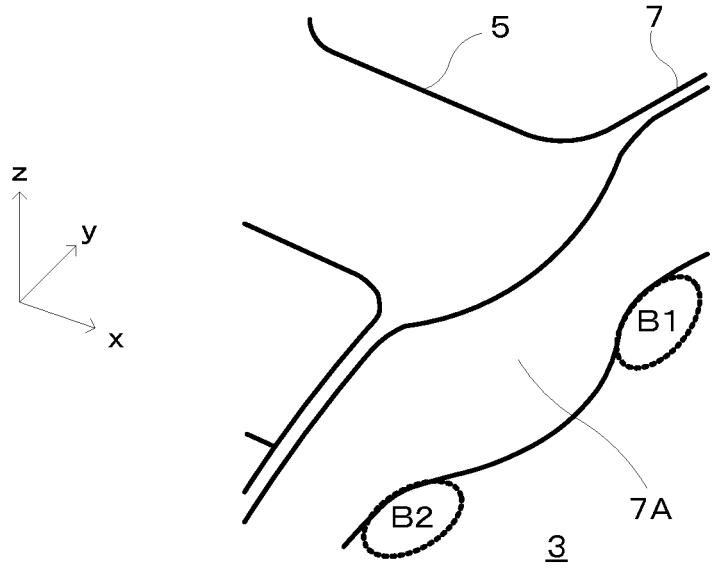


FIG. 11

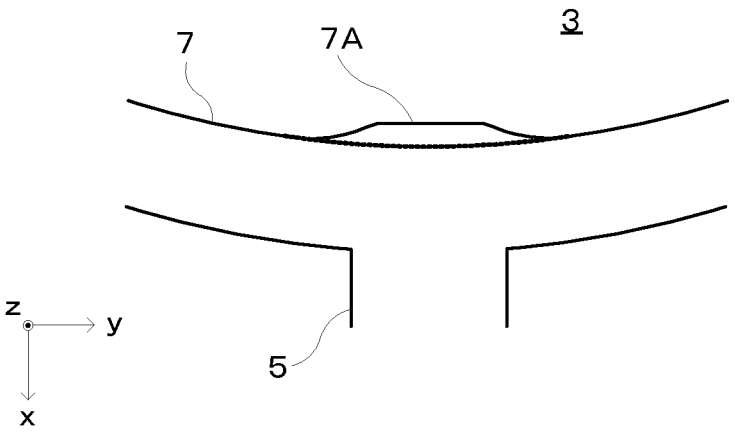


FIG.12

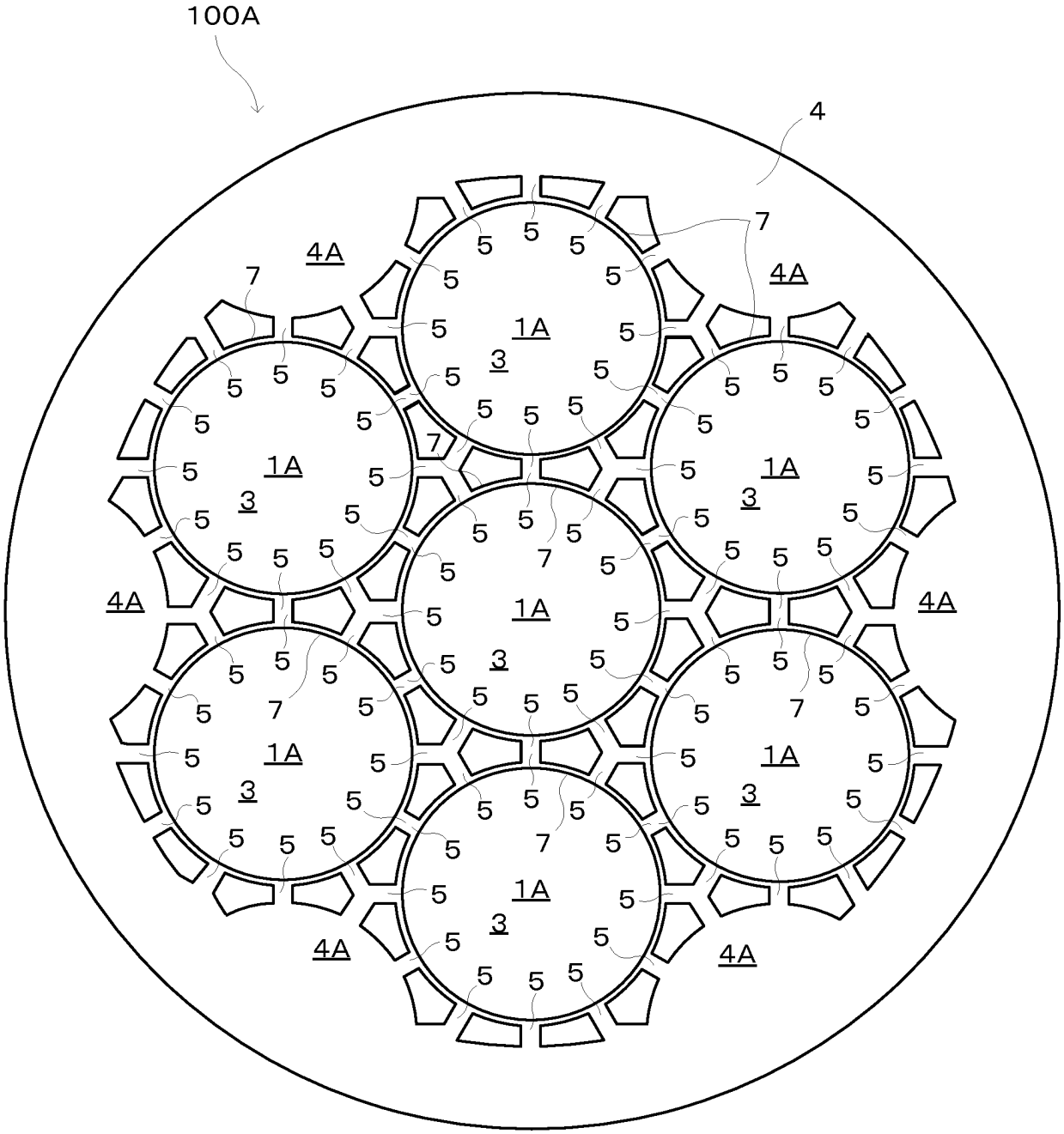


FIG.13

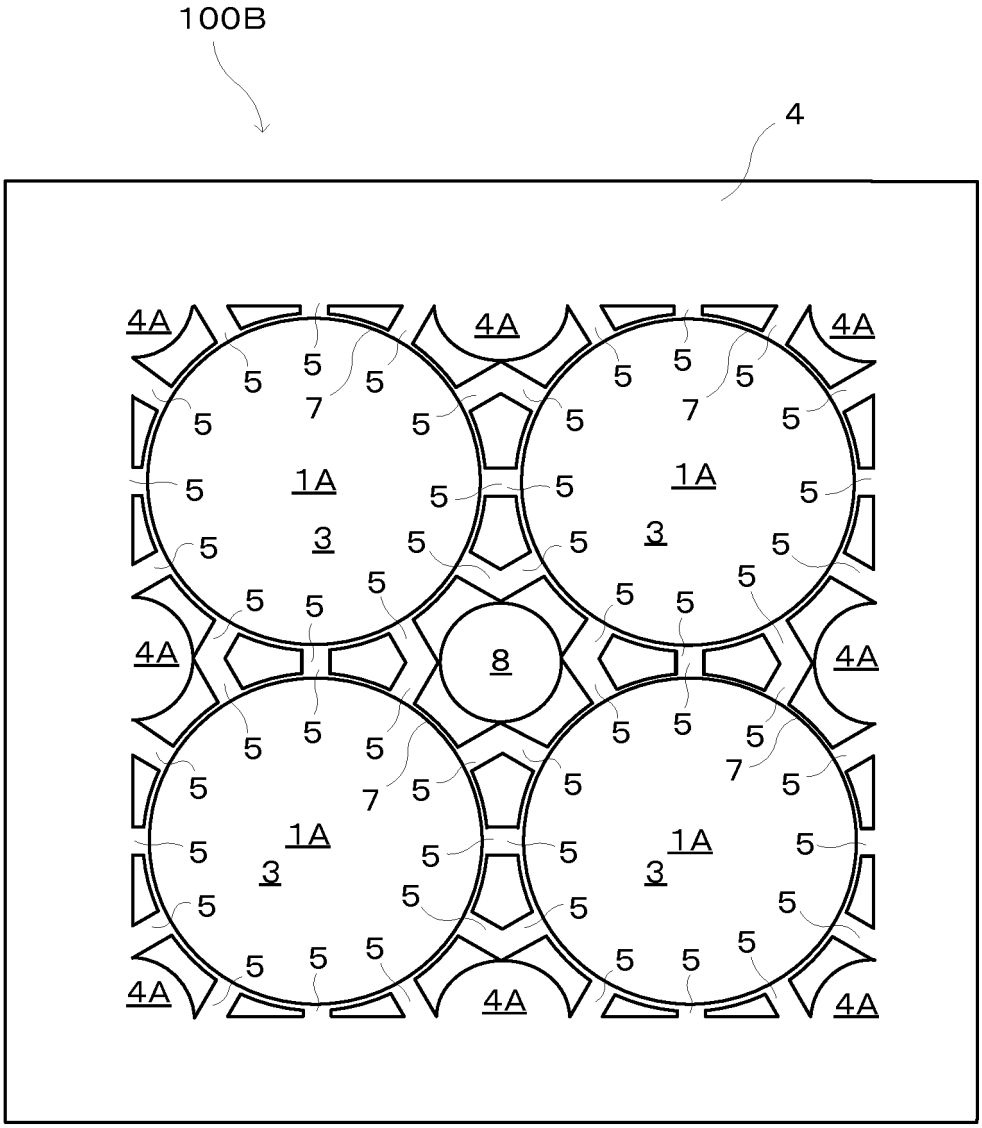


FIG.14

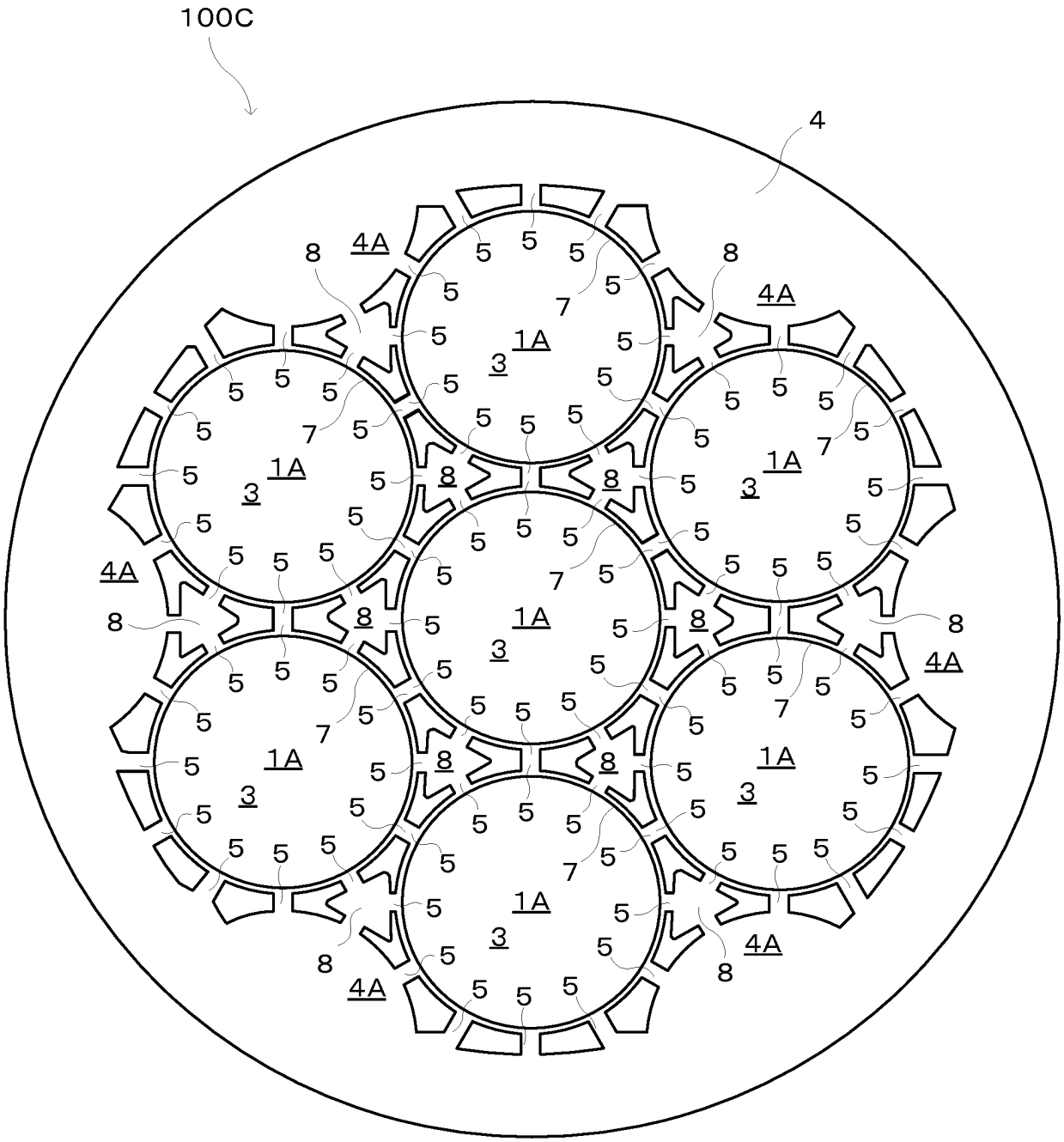
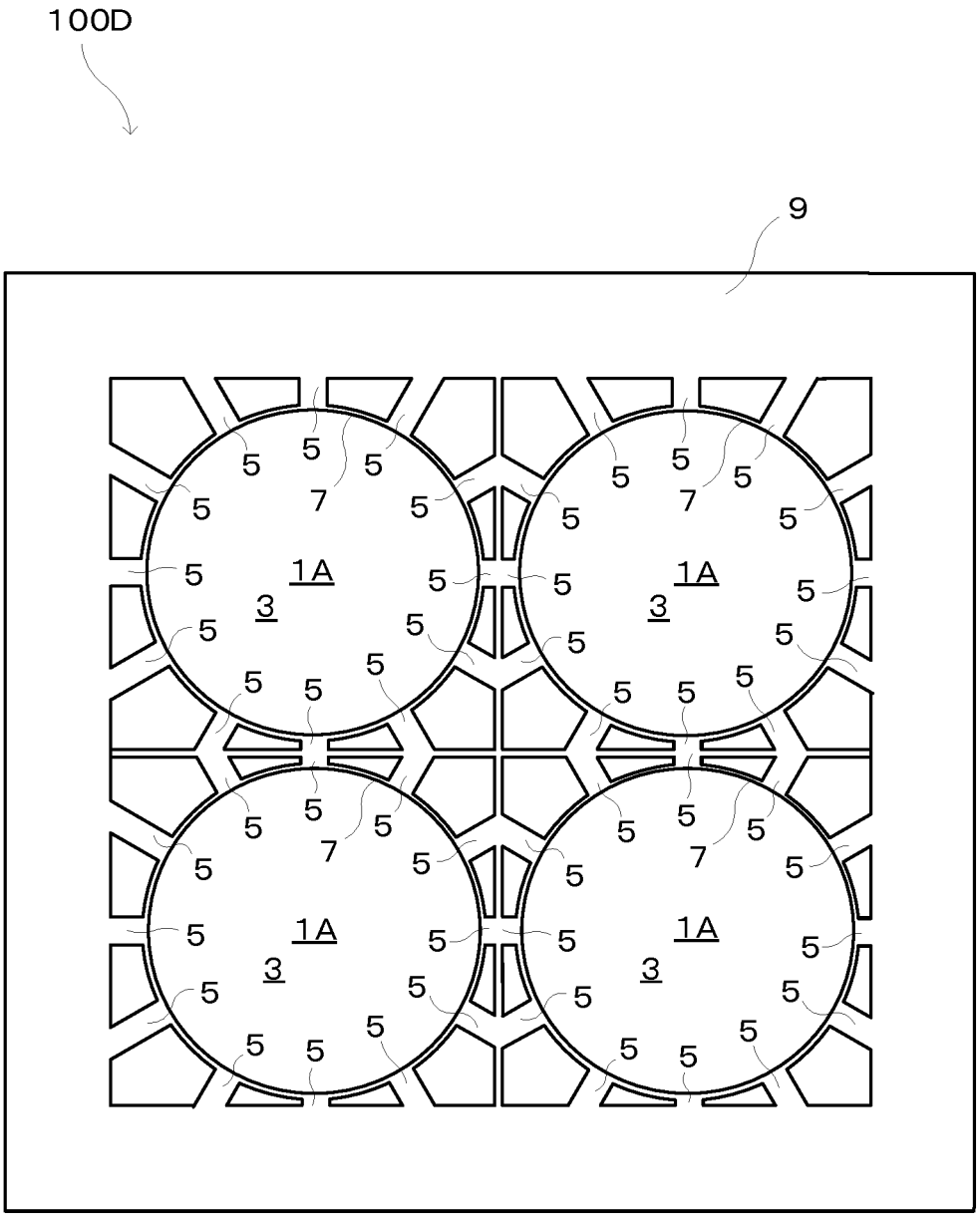


FIG.15



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/014286

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. H04R7/06(2006.01)i, H04R1/40(2006.01)i, H04R17/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int. Cl. H04R7/06, H04R1/40, H04R17/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2018
Registered utility model specifications of Japan 1996-2018
Published registered utility model applications of Japan 1994-2018

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2014-86941 A (NEC CASIO MOBILE COMMUNICATIONS, LTD.) 12 May 2014, paragraphs [0023]-[0028], [0046]-[0051], fig. 1, 2, 4 (Family: none)	1, 2, 6-12, 16 3-5, 13-15
A	JP 2012-15635 A (TAIHEIYO CEMENT CORP.) 19 January 2012, paragraphs [0056]-[0058], fig. 14 (Family: none)	10-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12.06.2018	19.06.2018

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

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Patent documents cited in the description

- JP 3123435 B **[0004]**
- JP 2017079686 A **[0088]**