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(71) Applicant (for all designated States except US): **SKY-
WORKS SOLUTIONS, INC.** [US/US]; 20 Sylvan
Road, Woburn, MA 01801 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **BARBER, Bradley,
P.** [US/US]; 370 Main Street, Acton, MA 01720 (US).
BI, Frank [US/US]; 7 Lantern Lane, Shrewsbury, MA
01545 (US). **CARPENTER, Craig, E.** [US/US]; 13
Morse Circle, Shirley, MA 01464 (US).

(74) Agent: **GATES, Sarah, M.**; Lowrie, Lando & Anastasi,
LLP, One Main Street, Eleventh Floor, Cambridge, MA
02142 (US).

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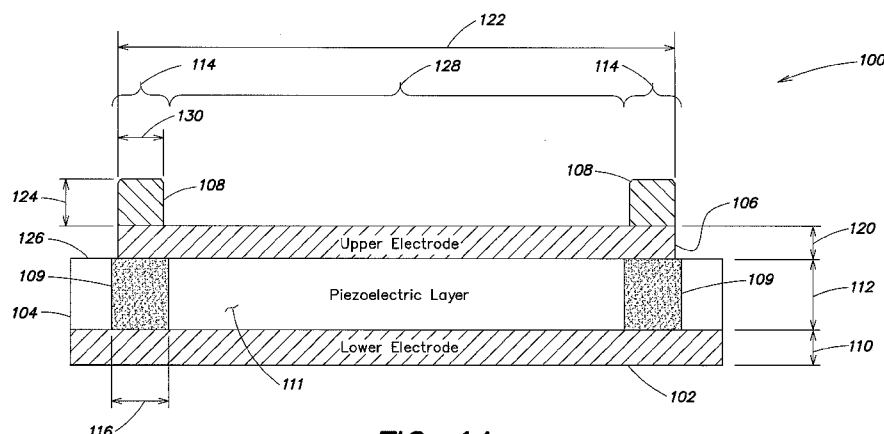


FIG. 1A

(57) Abstract: According to an exemplary embodiment, a bulk acoustic wave (BAW) resonator includes a piezoelectric layer situated between upper and lower electrodes, where each of the upper and lower electrodes are a high density metal. In one example, the BAW resonator further includes a controlled thickness region including a material segment that is one of a low density metal segment and a dielectric segment, where the material segment is situated adjacent to the piezoelectric layer, and where the controlled thickness region has controlled electromechanical coupling. The controlled thickness region can provide reduced electromechanical coupling into lateral modes. In another example, the piezoelectric layer has a disrupted texture region, where the disrupted texture region is situated in the controlled thickness region of the BAW resonator. The disrupted texture region can be situated at an edge of the BAW resonator and can extend along a perimeter of the BAW resonator.



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BULK ACOUSTIC WAVE RESONATOR

BACKGROUND OF THE INVENTION

Field of Invention

The present invention generally relates to the field of electronics. More particularly, the invention relates to bulk acoustic wave (BAW) resonators.

Discussion of Related Art

Because of their small footprint, low profile, and high performance, bulk acoustic wave (BAW) filters are increasingly utilized to provide radio frequency (RF) filtering in mobile electronic devices, such as cellular phones, as well as other types of electronic devices. BAW filters can include a number of BAW resonators, where each BAW resonator typically includes a layer of piezoelectric material, such as aluminum nitride, sandwiched between upper and lower electrodes. When an electric field is applied across the upper and lower electrodes of the BAW resonator, the electric field can cause the layer of piezoelectric material to vibrate. As a result, the piezoelectric material can generate a number of allowed modes of acoustic wave propagation, which include a desired longitudinal mode. However, unwanted excitation of energy in modes of wave propagation that have high energy loss, such as lateral modes, can cause a significant loss of energy in a BAW resonator and, thereby, undesirably lower the BAW resonator's quality factor (Q).

Conventional approaches to reducing energy loss in a BAW resonator include shaping the profile of the resonator such that the energy is best contained and controlled in a desired longitudinal mode. In one conventional profile shaping approach, a shaped region can be provided close to the edge of the BAW resonator, which is a region of high energy loss, to reduce the amount of energy that is excited in lossy modes of wave propagation in the BAW resonator. However, the shaped region provided in this conventional approach can also introduce additional unwanted modes, such as lateral modes contained within the shaped region, which can cause energy loss in the BAW resonator.

SUMMARY OF THE INVENTION

Aspects and embodiments are directed to bulk acoustic wave resonators with reduced energy loss and/or with a controlled thickness region having controlled electromechanical coupling.

According to one embodiment, a bulk acoustic wave (BAW) resonator comprises a piezoelectric layer situated between upper and lower electrodes, the upper and lower electrodes each comprising a high density metal, a controlled thickness region comprising a material segment, the material segment being situated adjacent to the piezoelectric layer, wherein the controlled thickness region has a controlled electromechanical coupling, and wherein the material segment comprises one of a low density metal segment and a dielectric segment.

In one example of the BAW resonator, the controlled thickness region provides reduced electromechanical coupling into lateral modes. In another example, the material segment is situated between the upper electrode and the piezoelectric layer. The material segment may extend along a perimeter of the BAW resonator. In one example, an edge of the upper electrode is self-aligned with an outside edge of the material segment. In another example, an edge of the upper electrode overlaps an outside edge of the material segment. The low density metal segment may comprise a metal selected from the group consisting of aluminum and titanium. The dielectric segment may comprise a low-k dielectric material. The low-k dielectric material may be selected from the group consisting of porous silica, fluorinated amorphous carbon, fluoro-polymer, parylene, polyarylene ether, hydrogen silsesquioxane (HSQ), fluorinated silicon dioxide, and diamond-like carbon. In one example, the material segment comprises the dielectric segment, and the dielectric segment is situated in contact with the piezoelectric layer, the dielectric segment being confined within a perimeter of the piezoelectric layer. In another example, the dielectric segment is situated at an edge of the BAW resonator.

Another embodiment is directed to a method of forming a BAW resonator, the method comprising acts of forming a piezoelectric layer over a lower electrode of the BAW resonator, forming a material segment over the piezoelectric layer in a controlled thickness region of the BAW resonator, the controlled thickness region having a controlled electromechanical coupling, and forming an upper electrode of the BAW resonator over the material segment, the upper electrode comprising a high density metal, wherein forming the material segment comprises one of forming a low density metal segment, and

forming a dielectric segment. In one example of the method, the controlled thickness region provides reduced electromechanical coupling into lateral modes. In another example, the forming of the upper electrode comprises forming an edge of the upper electrode concurrently with an outer edge of the material segment.

According to another embodiment, a bulk acoustic wave (BAW) resonator comprises a piezoelectric layer having a disrupted texture region, the disrupted texture region being situated in a controlled thickness region of the BAW resonator, and lower and upper electrodes situated on opposite surfaces of the piezoelectric layer, wherein the controlled thickness region has a controlled electromechanical coupling.

In one example of the BAW resonator, the controlled thickness region provides reduced electromechanical coupling into lateral modes. In another example, the controlled thickness region is situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator. The controlled thickness region may include a segment of material situated over the upper electrode. In one example, the segment of material is selected from the group consisting of a metal and a dielectric material. An outer edge of the segment of material may be self-aligned with an edge of the upper electrode. In another example, the BAW resonator further comprises a thin layer of silicon oxide underlying the disrupted texture region and situated between the lower electrode and the piezoelectric layer. The disrupted texture region may be situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator.

According to another embodiment, a method of forming a BAW resonator comprises acts of forming a lower electrode of the BAW resonator, forming a piezoelectric layer over the lower electrode, the piezoelectric layer comprising a disrupted texture region, the disrupted texture region being situated in a controlled thickness region of the BAW resonator, and forming an upper electrode of the BAW resonator over the piezoelectric layer, wherein the controlled thickness region has a controlled electromechanical coupling.

In one example, the method further comprises forming a segment of material over the upper electrode. Forming the segment of material may comprise forming a segment of material selected from the group consisting of a metal and a dielectric material. The method may further comprise an act of forming a thin layer of silicon oxide over a region of the lower electrode over which the disrupted texture region is to be formed prior to forming the piezoelectric layer. In another example, the method further comprises an act

of roughening a region of the lower electrode over which the disrupted texture region is to be formed prior to forming the piezoelectric layer.

According to another embodiment, a semiconductor die comprises at least one BAW resonator, the at least one BAW resonator comprising a piezoelectric layer having a disrupted texture region, the disrupted texture region situated in a controlled thickness region of the BAW resonator, and lower and upper electrodes situated on opposite surfaces of the piezoelectric layer, wherein the controlled thickness region has a controlled electromechanical coupling. In one example of the semiconductor die, the controlled thickness region provides reduced electromechanical coupling into lateral modes. In another example, the controlled thickness region is situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator. In another example, the controlled thickness region includes a segment of material situated over the upper electrode. The semiconductor die may be utilized in a circuit board as a part of an electronic system, the electronic system being selected from the group consisting of a wired or wireless communications device, a cell phone, a switching device, a router, a repeater, a codec, a wired or wireless LAN, a WLAN, a Bluetooth enabled device, a Global Positioning System (GPS) device, a computer, a monitor, a television set, a satellite set top box, a cable modem, a printer, a copier, an RF transceiver, and a personal digital assistant (PDA).

Still other aspects, embodiments, and advantages of these exemplary aspects and embodiments, are discussed in detail below. Moreover, it is to be understood that both the foregoing information and the following detailed description are merely illustrative examples of various aspects and embodiments, and are intended to provide an overview or framework for understanding the nature and character of the claimed aspects and embodiments. Any embodiment disclosed herein may be combined with any other embodiment in any manner consistent with the objects, aims, and needs disclosed herein, and references to “an embodiment,” “some embodiments,” “an alternate embodiment,” “various embodiments,” “one embodiment” or the like are not necessarily mutually exclusive and are intended to indicate that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment. The appearances of such terms herein are not necessarily all referring to the same embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of at least one embodiment are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. Where technical features in the figures, detailed description or any claim are followed by reference signs, the reference signs have been included for the sole purpose of increasing the intelligibility of the figures, detailed description, and claims. Accordingly, neither the reference signs nor their absence are intended to have any limiting effect on the scope of any claim elements. In the figures, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every figure. The figures are provided for the purposes of illustration and explanation and are not intended as a definition of the limits of the invention. In the figures:

Figure 1A is a cross-sectional view of one example of a bulk acoustic wave (BAW) resonator, in accordance with aspects of the invention;

Figure 1B is a top view of the example BAW resonator of Figure 1A;

Figure 2 is a flowchart illustrating one example of a method for fabricating a BAW resonator in accordance with aspects of the present invention;

Figure 3A is a cross-sectional view of another example of a BAW resonator, in accordance with aspects of the invention;

Figure 3B is a top view of the example BAW resonator of Figure 3A;

Figure 4A is a cross-sectional view of another example of a BAW resonator, in accordance with aspects of the invention;

Figure 4B is a top view of the example BAW resonator of Figure 4A;

Figure 5 is a flowchart illustrating another exemplary method for fabricating a BAW resonator in accordance with aspects of the present invention; and

Figure 6 is a diagram of an exemplary electronic system including an exemplary chip or die utilizing a BAW resonator in accordance with aspects of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Aspects and embodiments of the present invention are directed to bulk acoustic wave (BAW) resonators. For example, aspects and embodiments are directed to a BAW resonator with a controlled thickness region having controlled electromechanical coupling.

Other aspects and embodiments are directed to a BAW resonator with reduced energy loss, as discussed further below.

It is to be appreciated that embodiments of the methods and apparatuses discussed herein are not limited in application to the details of construction and the arrangement of components set forth in the following description or illustrated in the accompanying drawings. The methods and apparatuses are capable of implementation in other embodiments and of being practiced or of being carried out in various ways. Examples of specific implementations are provided herein for illustrative purposes only and are not intended to be limiting. In particular, acts, elements and features discussed in connection with any one or more embodiments are not intended to be excluded from a similar role in any other embodiments.

Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. Any references to embodiments or elements or acts of the systems and methods herein referred to in the singular may also embrace embodiments including a plurality of these elements, and any references in plural to any embodiment or element or act herein may also embrace embodiments including only a single element. References in the singular or plural form are not intended to limit the presently disclosed systems or methods, their components, acts, or elements. The use herein of “including,” “comprising,” “having,” “containing,” “involving,” and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. References to “or” may be construed as inclusive so that any terms described using “or” may indicate any of a single, more than one, and all of the described terms. Any references to front and back, left and right, top and bottom, and upper and lower are intended for convenience of description, not to limit the present systems and methods or their components to any one positional or spatial orientation.

Referring to Figure 1A, there is illustrated a cross-sectional view of an example of a BAW resonator 100, in accordance with one embodiment of the present invention. The BAW resonator 100 includes a lower electrode 102, a piezoelectric layer 104, an upper electrode 106, and a material segment 108. The BAW resonator 100 can further include an acoustic mirror, which provides acoustic isolation from an underlying substrate. The acoustic mirror and the substrate over which the BAW resonator 100 is fabricated are not shown in Figure 1A so as not to obscure the invention. In one embodiment, the BAW resonator 100 can be a film bulk acoustic resonator (FBAR) and can be acoustically

isolated from an underlying substrate by an air cavity. The BAW resonator 100 can be utilized in a BAW filter to provide RF filtering in a cellular phone or other type of semiconductor device and can be fabricated in a semiconductor die.

As shown in Figure 1A, the lower electrode 102 can be situated over, for example, an acoustic mirror, which is not shown in Figure 1A, and can comprise tungsten, molybdenum, or other suitable metal having a high density, (i.e., a high density metal). The lower electrode 102 has a thickness 110, which can be, for example, between 500.0 Angstroms and 5000.0 Angstroms. The lower electrode 102 can be formed by depositing a layer of high density metal, such as tungsten or molybdenum, over an underlying layer of material (not shown in Figure 1A) by utilizing a physical vapor deposition (PVD) or sputtering process or other suitable deposition process and appropriately patterning the layer of high density metal.

Also shown in Figure 1A, the piezoelectric layer 104 is situated over the lower electrode 102, includes a disrupted texture region 109 and a non-disrupted texture region 111, and has a top surface 126. A seed layer (not shown in Figure 1A) can be situated between the piezoelectric layer 104 and the lower electrode 102. The piezoelectric layer 104 can comprise aluminum nitride (AlN) or other suitable piezoelectric material and has thickness 112, which can be, for example, between 0.5 microns and 3.0 microns. The disrupted texture region 109 is situated in a controlled thickness region 114 at the edge of the BAW resonator 100 and extends along the entire perimeter of the BAW resonator 100. The disrupted texture region 109 has width 116, which can be, for example, between 1.0 micron and 5.0 microns. In the disrupted texture region 109, the crystallinity of the piezoelectric material is disrupted so as to cause significantly reduced electromechanical coupling therein. The non-disrupted texture region 111 is situated adjacent to and surrounded by the disrupted texture region 109 and comprises piezoelectric material having normal crystallinity, i.e., crystallinity that has not been intentionally disrupted. The piezoelectric layer 104 can be formed by, for example, depositing a layer of aluminum nitride over the lower electrode 102 by utilizing a PVD or sputtering process, a CVD process, or other suitable deposition process.

Prior to formation of the piezoelectric layer 104, the surface area that will underlie the disrupted texture region 109 can be sufficiently disturbed so as to ensure that the texture of the piezoelectric material will be disrupted when the piezoelectric layer 104 is formed. For example, a thin layer of material known to disrupt texture, such as silicon

oxide, can be deposited over a thin seed layer (not shown in Figure 1A) in the surface region of the lower electrode 102 over which the disrupted texture region 109 will be formed. As another example, an etch process or other suitable process can be utilized to roughen the surface region of the lower electrode 102 over which the disrupted texture region 109 will be formed. In one embodiment, the surface region of a layer (not shown in Figure 1A) underlying the region of the lower electrode 102 over which the material segment 108 will be formed can be roughened prior to forming the lower electrode 102. The resulting disruption in the texture of the lower electrode 102 caused by the roughening of the surface region of the underlying layer can, in turn, cause the texture of the piezoelectric material to be disrupted in disrupted texture region 109 when the piezoelectric layer 104 is formed.

Further shown in Figure 1A, the upper electrode 106 is situated over the piezoelectric layer 104 and can comprise tungsten, molybdenum, or other suitable dense metal. The upper electrode 106 has thickness 120, which can be, for example, between 500.0 Angstroms and 5000.0 Angstroms. The upper electrode 106 has width 122, which can be less than the width of the lower electrode 102 and which defines the width of the “active portion” of the BAW resonator 100. The “active portion” of BAW resonator 100 refers to the portion of piezoelectric layer 104 in which an electric field is applied to activate the resonator. In one embodiment, the upper electrode 106 and the lower electrode 102 can be approximately equal in width. The upper electrode 106 can be formed by depositing a layer of dense metal, such as tungsten or molybdenum, over the piezoelectric layer 104 by utilizing a PVD or sputtering process or other suitable deposition process. The layer of dense metal can be appropriately patterned by utilizing a suitable etch process. In the present embodiment, the edge of the upper electrode 106 can be self-aligned with the outer edge of the material segment 108 as discussed below.

Also shown in Figure 1A, the material segment 108 is situated over the upper electrode 106 at the edge of the BAW resonator 100. The material segment 108 is also situated in the controlled thickness region 114 and extends along the entire perimeter of the BAW resonator 100. The material segment 108 can comprise, for example, a metal, such as a low or high density metal, a dielectric material, or a semiconductor material and has thickness 124 and width 130. For example, thickness 124 of the material segment 108 can be between 100.0 Angstroms and 3000.0 Angstroms. Width 130 of the material segment 108 can be, for example, between 1.0 micron and 5.0 microns. In the

embodiment in Figure 1A, the material segment 108 has a uniform cross-sectional thickness. In other embodiments, the material segment 108 can have a non-uniform cross-sectional thickness and can have a wedge shape, a teardrop shape, or other suitable shape.

The material segment 108 can be formed by depositing a layer of material over the upper electrode 106 by utilizing a PVD or sputtering process, a CVD process, or other suitable deposition process. The layer of material can then be appropriately patterned by utilizing a suitable etch process to form the inner edge of the material segment 108. In the embodiment in Figure 1A, the outer edge of the material segment 108 can be formed concurrently with the edge of the upper electrode 106 in the same etch process so as to precisely define the edge of the BAW resonator 100. In one embodiment, the layer of material can be appropriately patterned by utilizing a suitable etch process to form the inner and outer edges of the material segment 108. In that embodiment, the material segment 108 can overlap the edge of the upper electrode 106 or fall entirely within its boundary.

Further shown in Figure 1A, the controlled thickness region 114 is situated at the edge of the BAW resonator 100 and includes the material segment 108, the disrupted texture region 109 of the piezoelectric layer 104, and the portion of the upper electrode 106 situated between the material segment 108 and the disrupted texture region 109. In another embodiment, the controlled thickness region 114 can be formed at a location other than at the edge of the BAW resonator 100. Also shown in Figure 1A, a high density metal region 128 is situated adjacent to and surrounded by the controlled thickness region 114 and includes the region of the BAW resonator 100 in which the upper electrode 106 is situated over the non-disrupted texture region 111 of the piezoelectric layer 104.

Figure 1B shows a top view of the BAW resonator 100, where the cross-sectional view of the BAW resonator 100 in Figure 1A is across line 1A-1A in Figure 1B. In particular, the piezoelectric layer 104, the upper electrode 106, the material segment 108, the disrupted texture region 109, the controlled thickness region 114, widths 116, 122, and 130, and the high density metal region 128 correspond to the same elements in Figure 1A and Figure 1B. As shown in Figure 1B, the upper electrode 106 has depth 132, which defines the approximate depth of the active region of the BAW resonator 100. In the embodiment in Figures 1A and 1B, the BAW resonator 100 has a rectangular shape. In one embodiment, the BAW resonator 100 can have a square shape, wherein width 122 can be approximately equal to depth 132. There can also be advantages to rounding the

corners of the BAW resonator 100 and/or forming the BAW resonator 100 such that opposite sides of the BAW resonator 100 are not parallel.

As shown in Figure 1B, the controlled thickness region 114 is situated at the edge of the BAW resonator 100, extends along the resonator's perimeter, and has a width that is defined by width 116 of the disrupted texture region 109. Also shown in Figure 1B, the material segment 108 is situated over the upper electrode 106 and the disrupted texture region 109 and is also situated at the edge of BAW resonator 100. The material segment 108 is further situated in the controlled thickness region 114 and extends along the perimeter of the BAW resonator 100.

The operation of the BAW resonator 100 will now be discussed. When an electric field is applied across the piezoelectric layer 104 via the upper electrode 106 and the lower electrode 102, electrical energy is converted into acoustic energy in the piezoelectric layer 104 through electromechanical coupling, thereby causing the piezoelectric layer 104 to vibrate. As a result, the piezoelectric layer 104 can generate acoustic waves that can propagate in a longitudinal mode, i.e., in a direction perpendicular to the top surface 126 of the piezoelectric layer 104, which is a desired mode. However, as a result of the crystalline structure of the piezoelectric layer 104, the edge region of the BAW resonator 100, and other factors, a multitude of other, unwanted modes of wave propagation can also be generated in the piezoelectric layer 104. For example, unwanted modes such as lateral modes, i.e., modes of acoustic wave propagation that occur in a direction parallel to the top surface 126 of the piezoelectric layer 104, can be generated in the piezoelectric layer 104. As discussed above, a significant loss of energy in BAW resonators can occur as a result of coupling energy into unwanted modes, such as lateral modes. In particular, the edge of a BAW resonator, such as the BAW resonator 100, is a lossy region of the resonator wherein coupling into unwanted, lossy modes, such as lateral modes, can undesirably increase energy loss in the BAW resonator 100.

In the BAW resonator 100, the controlled thickness region 114 includes the material segment 108, which is situated over the upper electrode 106 to provide thickness shaping at the edge of the BAW resonator 100, and the disrupted texture region 109, which comprises piezoelectric material having disrupted crystallinity. As a result, the electromechanical coupling can be controlled and, thereby, significantly reduced in the controlled thickness region 114. Thus, electromechanical coupling into unwanted modes, such as lateral modes, as well as coupling into the desired longitudinal mode, can be

significantly reduced in the controlled thickness region 114. However, the overall loss of coupling into the longitudinal mode in the BAW resonator 100 as a result of the loss of coupling in the controlled thickness region 114 is significantly less than the overall reduction in energy loss achieved in the BAW resonator 100 by reducing electromechanical coupling into unwanted modes in the controlled thickness region 114. Also, width 130, thickness 124, the composition of the material segment 108, and width 116 of the disrupted texture region 109 of the piezoelectric layer 104 can be appropriately selected to optimize reduction of coupling into unwanted modes, such as lateral modes.

Thus, by utilizing the disrupted texture region 109 of the piezoelectric layer 104 to reduce electromechanical coupling in controlled thickness region 114, an embodiment of the BAW resonator 100 achieves a significant reduction of electromechanical coupling into unwanted modes, thereby significantly reducing overall energy loss in the BAW resonator 100. By reducing overall energy loss, the invention advantageously achieves a BAW resonator having an increased Q.

From the above description of the examples in Figures 1A and 1B, it is manifest to one of ordinary skill in the art that the material segment 108 can alternatively be formed under the disrupted texture region 109 of the piezoelectric layer 104 and even under the lower electrode 102 in the BAW resonator 100 to achieve similar advantages as discussed above.

Figure 2 shows a flowchart illustrating an exemplary method according to one embodiment of the present invention. Certain details and features have been left out of flowchart 200 that are apparent to a person of ordinary skill in the art, given the benefit of this disclosure. For example, a step may consist of one or more sub-steps, or may involve specialized equipment or materials, as known in the art. It is also to be appreciated that the processing steps shown in flowchart 200 are performed on a portion of a processed wafer, which, prior to step 202 of flowchart 200, includes, among other things, an acoustic mirror or an air cavity overlying a substrate, which are not shown in any of the figures.

At step 202 of flowchart 200, lower electrode 102 of BAW resonator 100 in Figure 1A is formed over a substrate (not shown in any of the figures). In one embodiment, lower electrode 102 can be formed over an acoustic mirror (not shown in any of the figures), which can be formed over the substrate. In another embodiment, lower electrode 102 can be formed over an air cavity (not shown in any of the figures), which can be formed over the substrate. Lower electrode 102 can comprise a high density metal, such

as tungsten or molybdenum, and can be formed by depositing a layer of high density metal by utilizing a PVD or sputtering process or other suitable deposition process and appropriately patterning the layer of high density metal. At step 204, piezoelectric layer 104 is formed over lower electrode 102, where piezoelectric layer 104 includes disrupted texture region 109. In disrupted texture region 109, the crystallinity of the piezoelectric material is disrupted to significantly reduce electromechanical coupling in controlled thickness region 114, as discussed above.

Prior to formation of piezoelectric layer 104, the surface area that will underlie disrupted texture region 109 can be sufficiently disturbed so as to insure that the texture of the piezoelectric material will be disrupted when piezoelectric layer 104 is formed. For example, an etch process or other suitable process can be utilized to roughen the surface region of lower electrode 102 over which disrupted texture region 109 will be formed. This disruption can alternatively be done before the lower electrode is deposited since in some cases disruption of the lower electrode's texture will subsequently disrupt the piezoelectric material's texture. In one implementation, piezoelectric layer 104 can comprise aluminum nitride and can be formed by depositing a layer of aluminum nitride over lower electrode 102 by utilizing a PVD process or other suitable deposition process and appropriately patterning the layer of aluminum nitride. At step 206, upper electrode 106 of BAW resonator 100 is formed over piezoelectric layer 104. For example, upper electrode 106 can comprise a high density metal, such as tungsten or molybdenum, and can be formed by depositing a layer of high density metal over piezoelectric layer 104 by utilizing a PVD or sputtering process and appropriately patterning the layer of high density metal.

At step 208, material segment 108 is formed over upper electrode 106 in controlled thickness region 114 of BAW resonator 100. For example, material segment 108 can comprise a metal, a dielectric material, or a semiconductor material and can be formed by depositing a layer of the material over upper electrode 106 in controlled thickness region 114 by utilizing a CVD or other suitable deposition process. After deposition, the layer of material can be appropriately patterned by utilizing a suitable etch process. For example, the layer of material can be concurrently etched with an underlying layer of unpatterned high density metal such that the outer edge of material segment 108 is self-aligned with the edge of upper electrode 106.

Thus, as discussed above, in the examples in Figures 1A and 1B, embodiments of the invention provide a BAW resonator having a controlled thickness region that includes a material segment to provide thickness shaping and a disrupted texture region of a piezoelectric layer to provide controlled electromechanical coupling. By utilizing a controlled thickness region to reduce electromechanical coupling at the edge of the BAW resonator, the BAW resonator advantageously achieves a significant reduction in energy loss by significantly decreasing electromechanical coupling into unwanted, lossy modes compared to a conventional BAW resonator utilizing only profile shaping to reduce energy loss. As a result, the BAW resonator may advantageously achieve a higher Q compared to conventional BAW resonators.

Referring to Figures 3A and 3B, there is illustrated another embodiment of a BAW resonator in accordance with aspects of the invention. Figure 3A shows a cross-sectional view of a BAW resonator 300 which includes the lower electrode 102, piezoelectric layer 104 and upper electrode 106. BAW resonator 300 also includes a low density metal segment 302, as discussed further below. As discussed above with respect to BAW resonator 100, BAW resonator 300 may further include an acoustic mirror, which provides acoustic isolation from an underlying substrate. The acoustic mirror and substrate over which BAW resonator 300 is fabricated are not shown in Figure 3A. In one embodiment, BAW resonator 300 can be an FBAR and can be acoustically isolated from an underlying substrate by an air cavity. Similarly to BAW resonator 100, BAW resonator 300 can be utilized in a BAW filter to provide RF filtering in a cellular phone or other type of semiconductor device, and can be fabricated in a semiconductor die.

As shown in Figure 3A, low density metal segment 302 is situated over piezoelectric layer 104 in a controlled thickness region 114 of BAW resonator 300. Low density metal segment 302 can comprise, for example, aluminum, titanium, or another suitable low density metal, and has width 304 and thickness 306. In the example illustrated in Figure 3A, low density metal segment 302 is situated at the edge of BAW resonator 300, extends along the entire perimeter of the BAW resonator, and has a rectangular cross-sectional shape. In another example, low density metal segment 302 can be situated in a position other than at the edge of BAW resonator 300. In other examples, low density metal segment 302 may have a non-rectangular cross-sectional shape. Low density metal segment 302 has width 304 (i.e. a cross-sectional width), which can be, for example, between 1.0 micron and 5.0 microns. Low density metal segment 302 has

thickness 306, which can be, for example, between 100.0 Angstroms and 3000.0 Angstroms. It is noted that although low density metal segment 302 is shown as being thinner than upper electrode 106 for simplicity of illustration, low density metal segment 302 can also be thicker than or approximately equal in thickness to upper electrode 106.

Low density metal segment 302 can be formed, for example, by depositing a layer of low density metal, such as aluminum or titanium, over piezoelectric layer 104 by utilizing a PVD or sputtering process or other suitable deposition process. The layer of low density metal can then be appropriately patterned by utilizing a suitable etch process to form the inner edge of low density metal segment 302 by removing a center portion of the low density metal layer. In one embodiment, the outer edge of low density metal segment 302 can be self-aligned with the edge of upper electrode 106 by forming the outer edge of low density metal segment 302 concurrently with the edge of upper electrode 106 as discussed below. In one embodiment, the layer of low density metal can be appropriately patterned by utilizing a suitable etch process to form the inner and outer edges of low density metal segment 302. In that embodiment, upper electrode 106 can overlap the outer edge of low density metal segment 302 or be contained entirely within its boundary.

In the embodiment illustrated in Figure 3A, the layer of high density metal forming upper electrode 106 can be appropriately patterned by etching the layer of high density metal concurrently with the underlying layer of low density metal (utilized to form low density metal segment 302) in the same etch process, thereby providing a precisely defined edge of BAW resonator 300. Thus, in one embodiment, the edge of upper electrode 106 is self-aligned with the outer edge of low density metal segment 302. In one example, the layer of high density metal can overlap the previously formed outer edge of low density metal segment 302 and can be appropriately patterned by utilizing a suitable etch process.

As discussed above, controlled thickness region 114 is situated at the edge of BAW resonator 300 and extends along the edge of BAW resonator 300. In the example shown in Figure 3A controlled thickness region 114 includes low density metal segment 302 and portion 308 of upper electrode 106, which overlies low density metal segment 302. In another embodiment, controlled thickness region 114 can be formed at a location in BAW resonator 300 other than at the edge of the resonator. Also shown in Figure 3A, high density metal region 310 of BAW resonator 300 is situated adjacent to and

surrounded by controlled thickness region 114. In high density metal region 310, upper electrode 106 is situated on piezoelectric layer 104. Thus, in high density metal region 310, a low density metal segment, such as low density metal segment 302 is not disposed between upper electrode 106 and piezoelectric layer 104.

Figure 3B shows a top view of structure 300, where the cross-sectional view of BAW resonator 300 in Figure 3A is across line 3A-3A in Figure 3B. In particular, piezoelectric layer 104, upper electrode 106, controlled thickness region 114, widths 304 and 122, and high density metal region 310 correspond to the same elements in Figure 3A and Figure 3B. As shown in Figure 3B, upper electrode 106 has depth 312, which defines the approximate depth of the active region of BAW resonator 300. In the embodiment in Figures 3A and 3B, BAW resonator 300 has a rectangular shape. In another embodiment, BAW resonator 300 can have a square shape, wherein width 122 is approximately equal to depth 312. There can also be advantages to rounding the BAW resonator's corners, and/or forming the resonator such that opposite sides of the resonator are not parallel, as discussed above. As shown in Figure 3B, controlled thickness region 114 is situated at the edge of BAW resonator 300, extends along the resonator's perimeter, and has a width that is defined by width 304 of low density metal segment 302 (shown in Figure 3A). Also shown in Figure 3B, high density metal region 310 of BAW resonator 300 is situated adjacent to and enclosed by controlled thickness region 114.

The operation of BAW resonator 300 will now be discussed. As discussed above, unwanted lateral modes can be generated in piezoelectric layer 104 during operation of the BAW resonator 300, causing significant loss of energy in the BAW resonator. In one embodiment of BAW resonator 300, controlled thickness region 114 provides thickness shaping at the edge of BAW resonator 300 by adding low density metal segment 302 between upper electrode 106 and piezoelectric layer 104. This increases the thickness at edge of the resonator, thereby reducing energy loss into unwanted modes, such as lateral modes, by suppressing the unwanted modes. By utilizing a low density metal, such as aluminum or titanium, to form low density metal segment 302, where the low density metal has a lower density than the high density metal utilized to form upper electrode 106, electromechanical coupling can be significantly reduced in controlled thickness region 114. Thus, electromechanical coupling into unwanted modes, such as lateral modes can be significantly reduced in controlled thickness region 114. Coupling into the desired longitudinal mode is also reduced; however, the modest overall loss of coupling into the

longitudinal mode in BAW resonator 300 as a result of the loss of coupling in controlled thickness region 114 is warranted by the overall reduction in energy loss achieved in BAW resonator 300 by reducing electromechanical coupling into unwanted modes in controlled thickness region 114.

Thus, by reducing electromechanical coupling in controlled thickness region 114, a significant reduction in energy loss in BAW resonator 300 can be achieved by reducing electromechanical coupling into unwanted modes, such as lateral modes, in BAW resonator 300. Also, in controlled thickness region 114, width 304 and thickness 306 of low density metal segment 302 and thickness 120 of upper electrode 106 can be appropriately selected to achieve optimal reduction of energy loss in BAW resonator 300.

Thus, by controlling electromechanical coupling in controlled thickness region 114, the example illustrated in Figures 3A and 3B can achieve a significant reduction in the amount of energy that is coupled into lossy, unwanted modes, such as lateral modes, compared to a conventional BAW resonator that utilizes profile shaping to reduce loss. Thus, by reducing energy loss, an embodiment of BAW resonator 300 can advantageously provide an increased Q (quality factor) compared to a conventional BAW resonator.

From the above description of the embodiment of invention in Figures 3A and 3B, it is manifest to one of ordinary skill in the art that a controlled thickness region, such as controlled thickness region 114, can alternatively be formed between lower electrode 102 and piezoelectric layer 104 in BAW resonator 300 to achieve similar advantages as discussed above.

Figure 4A shows a cross-sectional view of another example of a BAW resonator 400, in accordance with one embodiment. BAW resonator 400 can be, for example, an FBAR and can be acoustically isolated from an underlying substrate by an air cavity. BAW resonator 400 can be utilized in a BAW filter to provide RF filtering in a cellular phone or other type of semiconductor device and can be fabricated in a semiconductor die.

In the example illustrated in Figure 4A, BAW resonator 400 includes a dielectric segment 402 situated on the top surface 126 of piezoelectric layer 104 in controlled thickness region 114 of BAW resonator 400. Dielectric segment 402 is also confined within a perimeter of piezoelectric layer 104. In other words, dielectric segment 402 does not extend beyond the edge of piezoelectric layer 104. However, it is important for dielectric segment 402 to be situated either on (i.e. in direct contact with) the top surface 126 of piezoelectric layer 104 (in the one embodiment) or on the bottom surface of

piezoelectric layer 204 (in another embodiment) for effective control of electromechanical coupling in controlled thickness region 114, as will be discussed below.

Dielectric segment 402 can comprise, for example, silicon oxide, silicon nitride, or other suitable dielectric material. In one embodiment, dielectric segment 402 can comprise a “low dielectric constant (low-k) dielectric material,” such as porous silica, fluorinated amorphous carbon, fluoro-polymer, parylene, polyarylene ether, hydrogen silsesquioxane (HSQ), fluorinated silicon dioxide, or diamond-like carbon. In the one application, a “low-k dielectric material” is defined as a dielectric material having a dielectric constant that is less than the dielectric constant of silicon oxide.

In the example shown in Figure 4A, dielectric segment 402 is situated at the edge of BAW resonator 400, extends along the entire perimeter of the BAW resonator, and has a rectangular cross-sectional shape. In one embodiment, dielectric segment 402 can be situated in close proximity to the edge of BAW resonator 400. In another embodiment, dielectric segment 402 can have a non-rectangular cross-sectional shape. Dielectric segment 402 has width 404, which can be, for example, between 1.0 micron and 5.0 microns. Dielectric segment 402 has thickness 406, which can be, for example, between 100.0 Angstroms and 3000.0 Angstroms. It is noted that although dielectric segment 402 is shown as being thinner than upper electrode 106 for simplicity of illustration, dielectric segment 402 can also be thicker than or approximately equal in thickness to upper electrode 106.

Dielectric segment 402 can be formed, for example, by depositing a layer of dielectric material, such as silicon oxide, over piezoelectric layer 104 by utilizing a CVD process or other suitable deposition process. The layer of dielectric material can then be appropriately patterned by utilizing a suitable etch process to form the inner edge of dielectric segment 402 by removing a center portion of the dielectric layer. In the embodiment in Figure 4A, the outer edge of dielectric segment 402 can be self-aligned with the edge of upper electrode 106. For example, upper electrode 106 can be formed by depositing a layer of high density metal, such as tungsten or molybdenum, over piezoelectric layer 104 and dielectric segment 402 by utilizing a PVD or sputtering process or other suitable deposition process. The layer of high density metal can be appropriately patterned by etching the layer of high density metal concurrently with the underlying layer of dielectric material utilized to form dielectric segment 402, so as to precisely define the edge of BAW resonator 400. Thus, in the embodiment in Figure 4A,

the edge of upper electrode 106 is self-aligned with the outer edge of dielectric segment 402. In another embodiment, the layer of high density metal can overlap the outer edge of dielectric segment 402 and can be appropriately patterning by utilizing a suitable etch process to form the edge of upper electrode 106. In another embodiment, the layer of dielectric material can be appropriately patterned by utilizing a suitable etch process to form the inner and outer edges of dielectric segment 402. In that embodiment, upper electrode 106 can overlap the outside edge of dielectric segment 402 or be contained entirely within its boundary.

Also shown in Figure 4A, controlled thickness region 114 is situated at the edge of BAW resonator 400, extends along the edge of BAW resonator 400, and includes dielectric segment 402 and portion 308 of upper electrode 106, which overlies dielectric segment 402. In another embodiment, controlled thickness region 114 can be formed at a location in BAW resonator 400 other than at the edge of resonator. In the embodiment in Figure 4A, controlled thickness region 114 has a uniform cross-sectional thickness. As discussed above, in other embodiments, controlled thickness region 114 can have a non-uniform cross sectional thickness and a non-rectangular cross-sectional shape, such as, for example, a wedge shape or a teardrop shape. Further shown in Figure 4A, high density metal region 408 of BAW resonator 400 is situated adjacent to and surrounded by controlled thickness region 114. In high density metal region 408, upper electrode 106 is situated on piezoelectric layer 104. Thus, in high density metal region 408, a dielectric segment, such as dielectric segment 402, is not disposed between upper electrode 106 and piezoelectric layer 104.

Figure 4B shows a top view of structure 400, where the cross-sectional view of BAW resonator 400 in Figure 4A is across line 4A-4A in Figure 4B. In particular, piezoelectric layer 104, upper electrode 106, controlled thickness region 114, widths 404 and 122, and high density metal region 408 correspond to the same elements in Figure 4A and Figure 4B. As discussed above, although in Figures 4A and 4B, BAW resonator 400 has a rectangular shape, BAW resonator 400 can alternatively have a square shape, wherein width 122 is approximately equal to depth 312. There can also be advantages to rounding the BAW resonator's corners and/or forming the resonator such that opposite sides of the resonator are not parallel, as discussed above. As shown in Figure 4B, controlled thickness region 114 is situated at the edge of BAW resonator 400, extends along the resonator's perimeter, and has a width that is defined by width 404 of dielectric

segment 403. Also shown in Figure 4B, high density metal region 408 of BAW resonator 400 is situated adjacent to and enclosed by controlled thickness region 114.

The operation of BAW resonator 400 will now be discussed. As discussed above, unwanted lateral modes can be generated in piezoelectric layer 104 during operation of the BAW resonator 400, causing significant loss of energy in the BAW resonator. In BAW resonator 400, controlled thickness region 114 provides thickness shaping at the edge of BAW resonator 400 by adding dielectric segment 402 between upper electrode 106 and piezoelectric layer 104. Control of electromechanical coupling is also provided by utilizing dielectric segment 402, which operates electrically as a series capacitor to reduce the electric field in controlled thickness region 114. By reducing the electric field in controlled thickness region 114, the electromechanical coupling in controlled thickness region 114 is correspondingly reduced.

By reducing electromechanical coupling in controlled thickness region 114, electromechanical coupling into unwanted modes, such as lateral modes, is reduced. Coupling into the desired longitudinal mode is also reduced; however, the overall modest loss of coupling into the longitudinal mode in BAW resonator 400 as a result of the loss of coupling in controlled thickness region 114 is warranted by the overall reduction in energy loss achieved in BAW resonator 400 by reducing electromechanical coupling into unwanted modes in controlled thickness region 114.

Thus, by reducing electromechanical coupling in controlled thickness region 114, a significant reduction in energy loss in BAW resonator 400 can be achieved by reducing electromechanical coupling into unwanted modes, such as lateral modes, in BAW resonator 400. Also, in controlled thickness region 114, width 404 and thickness 406 of dielectric segment 402 and thickness 120 of upper electrode 106 can be appropriately selected to achieve optimal reduction of energy loss in BAW resonator 400.

Thus, by controlling electromechanical coupling in controlled thickness region 114, the embodiment of Figures 4A and 4B can achieve a significant reduction in the amount of energy that is coupled into lossy, unwanted modes, such as lateral modes, compared to a conventional BAW resonator that utilizes profile shaping to reduce energy loss. Thus, by reducing energy loss, the embodiment of the BAW resonator 400 can advantageously provide an increased Q (quality factor) compared to a conventional BAW resonator.

From the above description of the embodiment of invention in Figures 4A and 4B, it is manifest to one of ordinary skill in the art that a controlled thickness region, such as controlled thickness region 114, can alternatively be formed such that a dielectric segment, such as dielectric segment 402, is situated between lower electrode 102 and piezoelectric layer 104 in BAW resonator 400 to achieve similar advantages as discussed above.

Referring to Figure 5, there is illustrated a flowchart illustrating an exemplary method according to one embodiment. Certain details and features have been left out of flowchart 500 that are apparent to a person of ordinary skill in the art. For example, a step may consist of one or more substeps or may involve specialized equipment or materials, as known in the art. It is noted that the processing steps shown in flowchart 500 are performed on a portion of a processed wafer, which, prior to step 202 of flowchart 500, includes, among other things, an acoustic mirror or an air cavity overlying a substrate, which are not shown in any of the figures. As discussed above, at step 202, the lower electrode 102 of the BAW resonator is formed over a substrate. At step 504, the piezoelectric layer 104 is formed over the lower electrode 102.

At step 506, a segment of material, such as low density metal segment 302 in Figure 3A or dielectric segment 402 in Figure 4A, is formed over the piezoelectric layer 104 in a controlled thickness region of the BAW resonator, such as controlled thickness region 114. For example, low density metal segment 302, which can comprise a low density metal such as aluminum or titanium, can be formed over piezoelectric layer 104 in controlled thickness region 114 of BAW resonator 300 by utilizing a PVD or sputtering process. For example, dielectric segment 402, which can comprise a dielectric material such as silicon oxide, silicon nitride, or a low-k dielectric material, can be formed over piezoelectric layer 104 in controlled thickness region 114 of BAW resonator 400 by utilizing a CVD or other suitable deposition process.

At step 508, upper electrode is formed over the segment of material, such as low density metal segment 302 or dielectric segment 402, and over the piezoelectric layer 104. For example, upper electrode 106 can comprise a high density metal, such as tungsten or molybdenum, and can be formed by depositing a layer of high density metal over low density metal segment 302, or dielectric segment 402, and over piezoelectric layer 104 by utilizing a sputtering process and appropriately patterning the high density metal layer. For example, the layer of high density metal can be etched concurrently with an underlying layer of material such that the edge of the upper electrode, such as upper

electrode 106 is self-aligned with an outer edge of the underlying segment of material, such as an outer edge of respective low density metal segment 302 or dielectric segment 402.

Thus, as discussed above in relation to the embodiments in Figures 3A and 3B as well as 4A and 4B, aspects and embodiments provide a BAW resonator including a controlled thickness region, wherein the controlled thickness region provides a shaped thickness and controlled electromechanical coupling. By utilizing a controlled thickness region to reduce electromechanical coupling at the edge of the BAW resonator, the BAW resonator may advantageously achieve a significant reduction in energy loss by significantly decreasing electromechanical coupling into unwanted, lossy modes compared to a conventional BAW resonator utilizing only profile shaping to reduce energy loss. As a result, the BAW resonator may advantageously achieve a higher Q compared to the conventional BAW resonator.

Figure 6 illustrates a diagram of an exemplary electronic system including an exemplary chip or die utilizing one or more BAW resonators in accordance with one embodiment. An electronic system 600 includes exemplary modules 602, 604, and 606, an IC chip or semiconductor die 608, discrete components 610 and 612, residing in and interconnected through a circuit board 614. In one embodiment, the electronic system 600 may include more than one PCB. The IC chip 608 includes a circuit 616, which can comprise a BAW filter, including one or more of the BAW resonators designated by a numeral 618.

As shown in Figure 6, the modules 602, 604, and 606 are mounted on the circuit board 614 and can each be, for example, a central processing unit (CPU), a graphics controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a video processing module, an audio processing module, an RF receiver, an RF transmitter, an image sensor module, a power control module, an electro-mechanical motor control module, or a field programmable gate array (FPGA), or any other kind of module utilized in modern electronic circuit boards. The circuit board 614 can include a number of interconnect traces (not shown in Figure 6) for the interconnecting modules 602, 604, and 606, the discrete components 610 and 612, and the IC chip 608.

Also shown in Figure 6, the IC chip 608 is mounted on the circuit board 614 and can be, for example, any chip utilizing one or more of an embodiment of BAW resonators discussed above, such as any of BAW resonators 100, 300 and 400. In one embodiment,

the IC chip 608 may not be mounted on the circuit board 614, and may be interconnected with other modules on different circuit boards. As stated above, the circuit 616 is situated in the IC chip 608 and can comprise a BAW filter including one or more of the BAW resonators designed by the numeral 618. Further shown in Figure 6, the discrete components 610 and 612 are mounted on the circuit board 614 and can each be, for example, a discrete filter, such as one including a SAW filter or the like, a power amplifier or an operational amplifier, a semiconductor device, such as a transistor or a diode or the like, an antenna element, an inductor, a capacitor, or a resistor.

The electronic system 600 can be utilized in, for example, a wired or wireless communications device, a cell phone, a switching device, a router, a repeater, a codec, a wired or wireless LAN, a WLAN, a Bluetooth enabled device, a Global Positioning System (GPS) device, a computer, a monitor, a television set, a satellite set top box, a cable modem, a printer, a copier, an RF transceiver, a personal digital assistant (PDA), or in any other kind of system, device, component or module utilized in modern electronics applications.

Having thus described several aspects of at least one embodiment, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure and are intended to be within the scope of the invention. The examples discussed herein serve to illustrate some of the novel features, aspect and examples of the technology disclosed herein and should not be construed as limiting the scope of the appended claims. Accordingly, the foregoing description and drawings are by way of example only, and the scope of the invention should be determined from proper construction of the appended claims, and their equivalents.

CLAIMS

1. A bulk acoustic wave (BAW) resonator comprising:
a piezoelectric layer situated between upper and lower electrodes, the upper and lower electrodes each comprising a high density metal;
a controlled thickness region comprising a material segment, the material segment being situated adjacent to the piezoelectric layer;
wherein the controlled thickness region has a controlled electromechanical coupling; and
wherein the material segment comprises one of a low density metal segment and a dielectric segment.
2. The BAW resonator of claim 1, wherein the controlled thickness region provides reduced electromechanical coupling into lateral modes.
3. The BAW resonator of claim 1, wherein the material segment is situated between the upper electrode and the piezoelectric layer.
4. The BAW resonator of claim 1, wherein the material segment extends along a perimeter of the BAW resonator.
5. The BAW resonator of claim 3, wherein an edge of the upper electrode is self-aligned with an outside edge of the material segment.
6. The BAW resonator of claim 3, wherein an edge of the upper electrode overlaps an outside edge of the material segment.
7. The BAW resonator of claim 1, wherein the low density metal segment comprises a metal selected from the group consisting of aluminum and titanium.
8. The BAW resonator of claim 1, wherein the dielectric segment comprises a low-k dielectric material.

9. The BAW resonator of claim 8, wherein the low-k dielectric material is selected from the group consisting of porous silica, fluorinated amorphous carbon, fluoro-polymer, parylene, polyarylene ether, hydrogen silsesquioxane (HSQ), fluorinated silicon dioxide, and diamond-like carbon.
10. The BAW resonator of claim 1, wherein the material segment comprises the dielectric segment; and
wherein the dielectric segment is situated in contact with the piezoelectric layer, the dielectric segment being confined within a perimeter of the piezoelectric layer.
11. The BAW resonator of claim 10, wherein the dielectric segment is situated at an edge of the BAW resonator.
12. A method of forming a BAW resonator, the method comprising:
forming a piezoelectric layer over a lower electrode of the BAW resonator;
forming a material segment over the piezoelectric layer in a controlled thickness region of the BAW resonator, the controlled thickness region having a controlled electromechanical coupling;
forming an upper electrode of the BAW resonator over the material segment, the upper electrode comprising a high density metal;
wherein forming the material segment comprises one of:
forming a low density metal segment; and
forming a dielectric segment.
13. The method of claim 12, wherein the controlled thickness region provides reduced electromechanical coupling into lateral modes.
14. The method of claim 12, wherein the forming of the upper electrode comprises forming an edge of the upper electrode concurrently with an outer edge of the material segment.

15. A bulk acoustic wave (BAW) resonator comprising:
a piezoelectric layer having a disrupted texture region, the disrupted texture region being situated in a controlled thickness region of the BAW resonator; and
lower and upper electrodes situated on opposite surfaces of the piezoelectric layer;
wherein the controlled thickness region has a controlled electromechanical coupling.
16. The BAW resonator of claim 15, wherein the controlled thickness region provides reduced electromechanical coupling into lateral modes.
17. The BAW resonator of claim 15, wherein the controlled thickness region is situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator.
18. The BAW resonator of claim 15, wherein the controlled thickness region includes a segment of material situated over the upper electrode.
19. The BAW resonator of claim 18, wherein the segment of material is selected from the group consisting of a metal and a dielectric material.
20. The BAW resonator of claim 18, wherein an outer edge of the segment of material is self-aligned with an edge of the upper electrode.
21. The BAW resonator of claim 15, further comprising a thin layer of silicon oxide underlying the disrupted texture region and situated between the lower electrode and the piezoelectric layer.
22. The BAW resonator of claim 15, wherein the disrupted texture region is situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator.

23. A method of forming a BAW resonator, the method comprising:
forming a lower electrode of the BAW resonator;
forming a piezoelectric layer over the lower electrode, the piezoelectric layer comprising a disrupted texture region, the disrupted texture region being situated in a controlled thickness region of the BAW resonator; and
forming an upper electrode of the BAW resonator over the piezoelectric layer;
wherein the controlled thickness region has a controlled electromechanical coupling.
24. The method of claim 23, further comprising forming a segment of material over the upper electrode.
25. The method of claim 24, wherein forming the segment of material comprises forming a segment of material selected from the group consisting of a metal and a dielectric material.
26. The method of claim 23, further comprising forming a thin layer of silicon oxide over a region of the lower electrode over which the disrupted texture region is to be formed prior to forming the piezoelectric layer.
27. The method of claim 23, further comprising roughening a region of the lower electrode over which the disrupted texture region is to be formed prior to forming the piezoelectric layer.
28. A semiconductor die comprising at least one BAW resonator, the at least one BAW resonator comprising:
a piezoelectric layer having a disrupted texture region, the disrupted texture region situated in a controlled thickness region of the BAW resonator; and
lower and upper electrodes situated on opposite surfaces of the piezoelectric layer;
wherein the controlled thickness region has a controlled electromechanical coupling.
29. The semiconductor die of claim 28, wherein the controlled thickness region provides reduced electromechanical coupling into lateral modes.

30. The semiconductor die of claim 28, wherein the controlled thickness region is situated at an edge of the BAW resonator and extends along a perimeter of the BAW resonator.

31. The semiconductor die of claim 28, wherein the controlled thickness region includes a segment of material situated over the upper electrode.

32. The semiconductor die of claim 28, wherein the semiconductor die is utilized in a circuit board as a part of an electronic system, the electronic system being selected from the group consisting of a wired or wireless communications device, a cell phone, a switching device, a router, a repeater, a codec, a wired or wireless LAN, a WLAN, a Bluetooth enabled device, a Global Positioning System (GPS) device, a computer, a monitor, a television set, a satellite set top box, a cable modem, a printer, a copier, an RF transceiver, and a personal digital assistant (PDA).

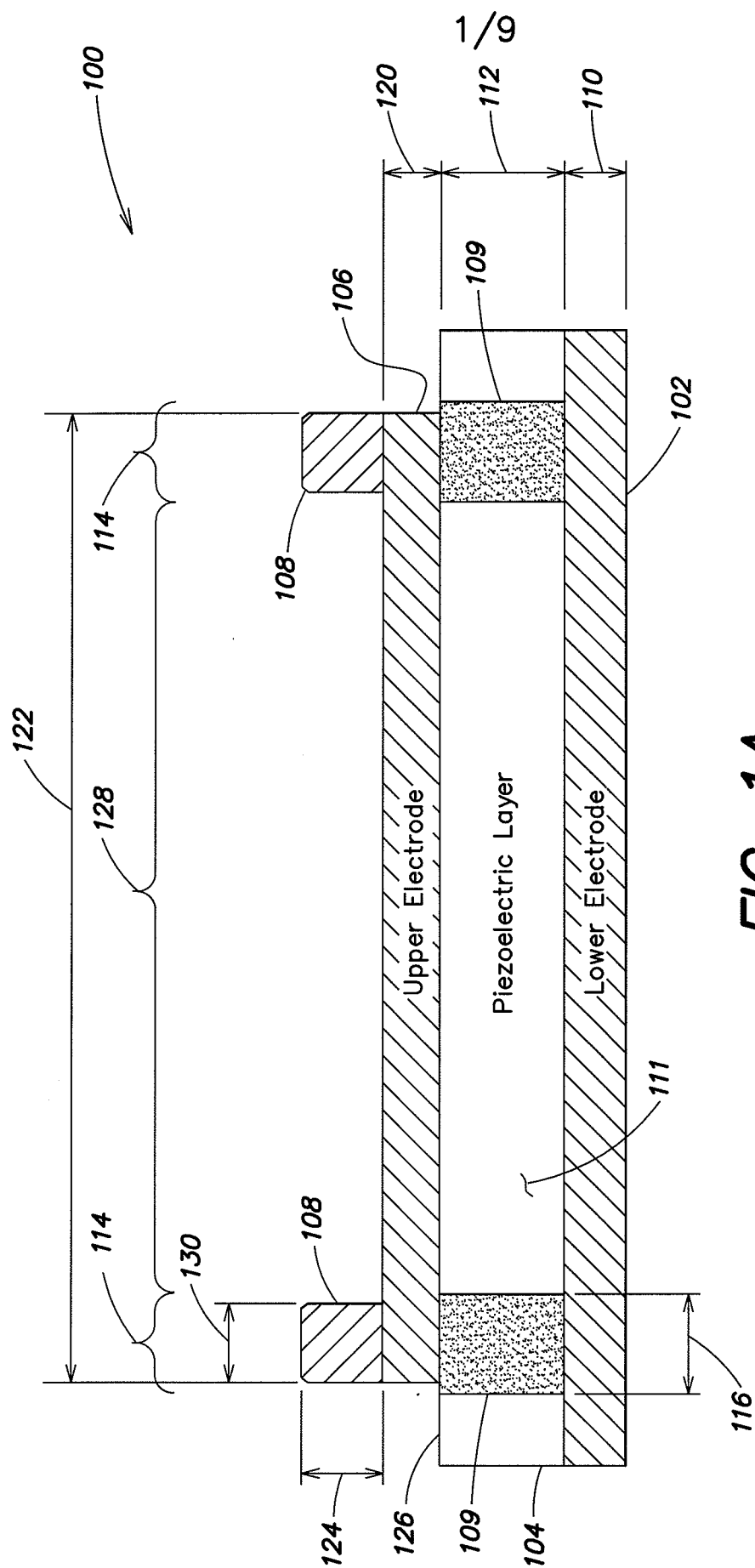
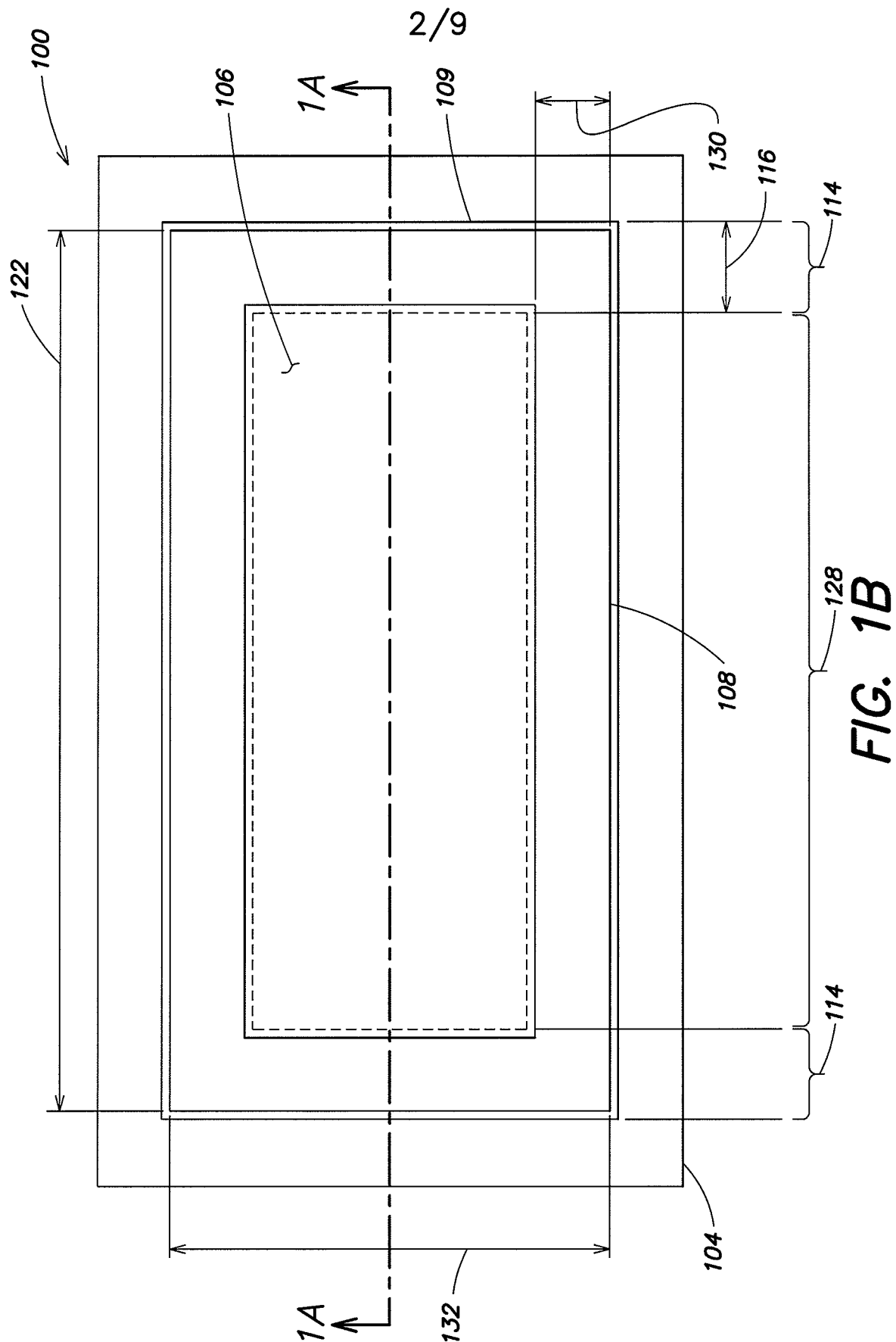
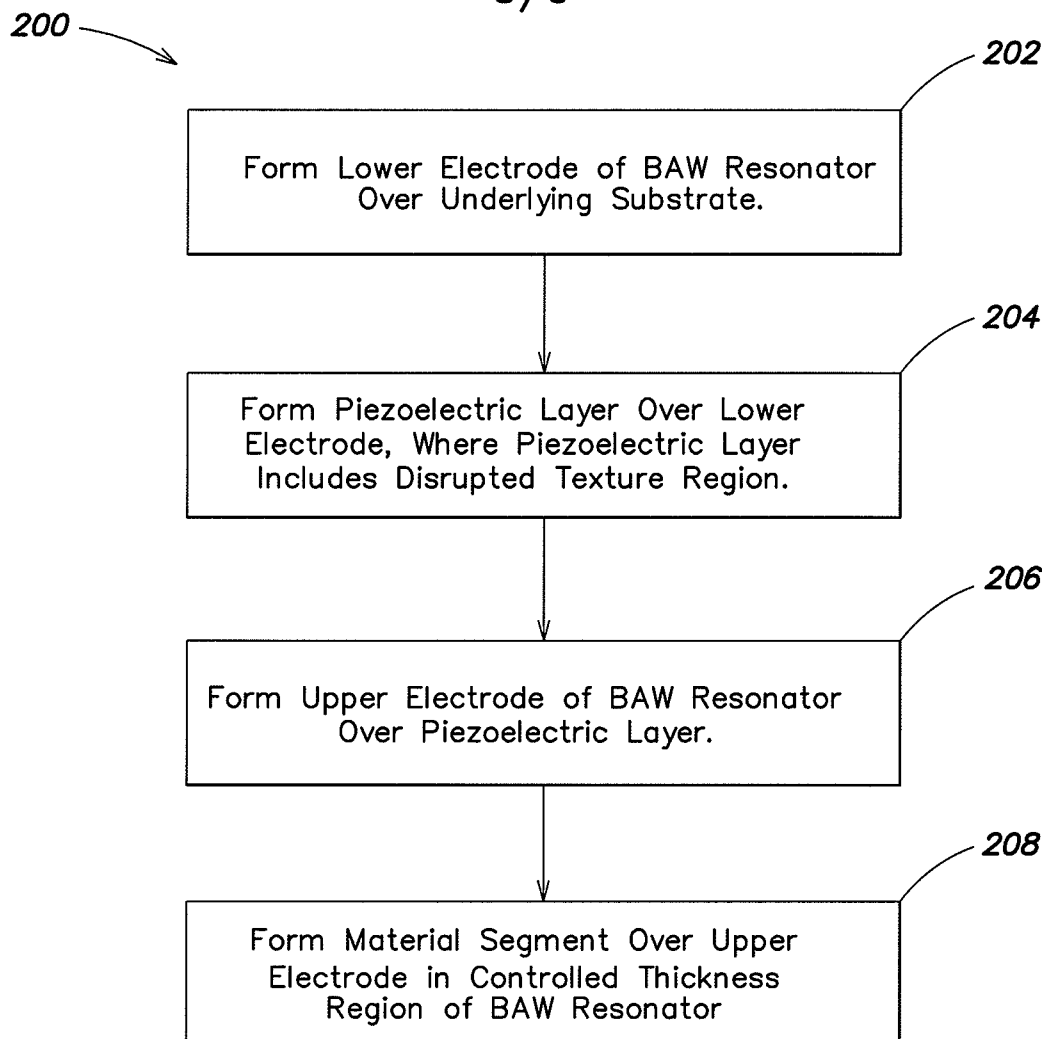


FIG. 1A



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**FIG. 2**

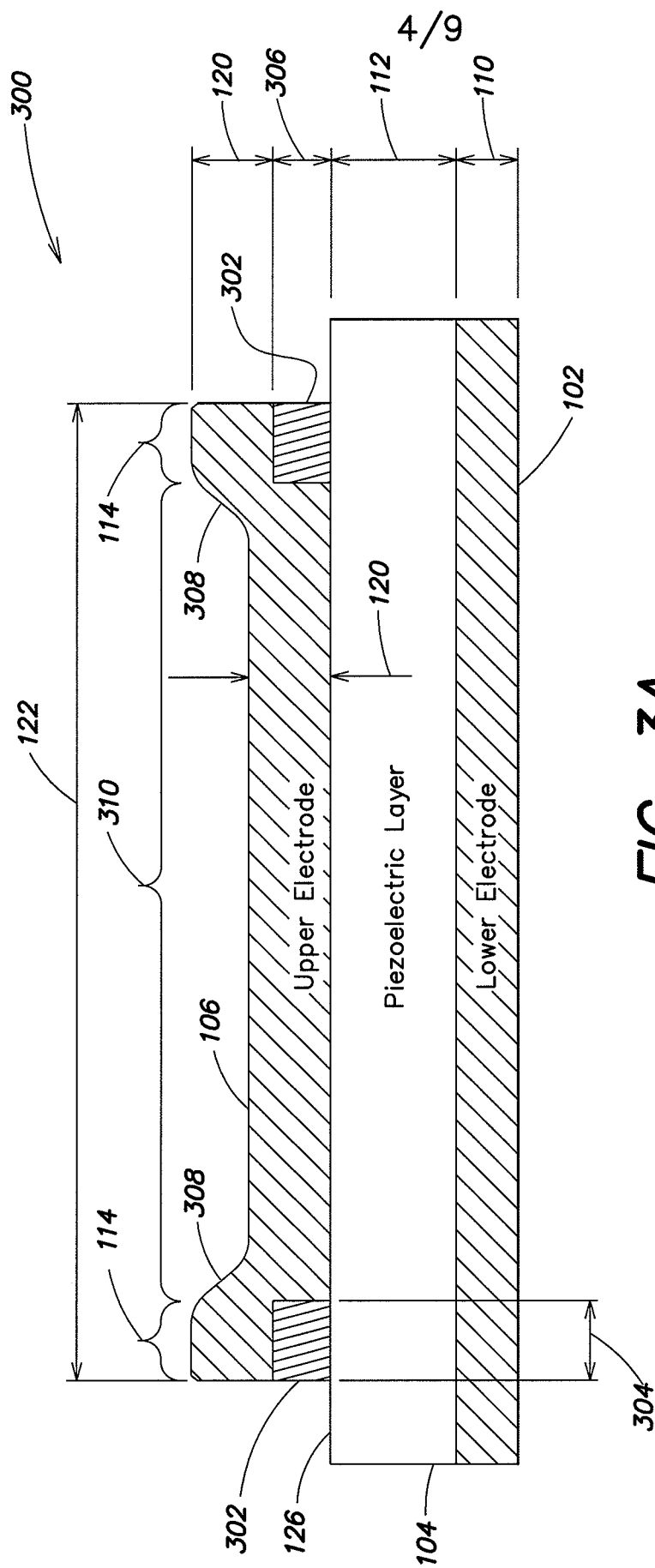


FIG. 3A

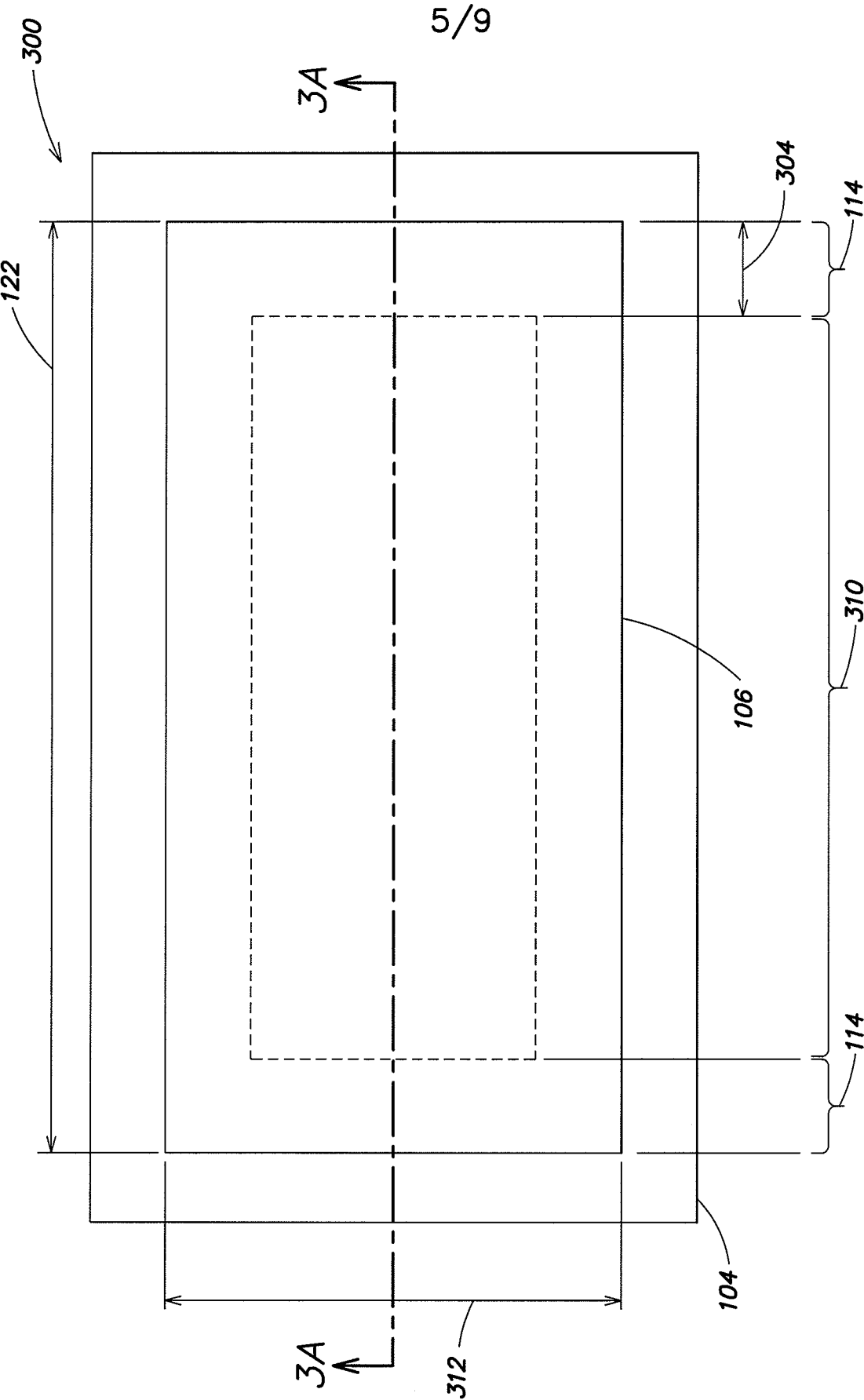


FIG. 3B

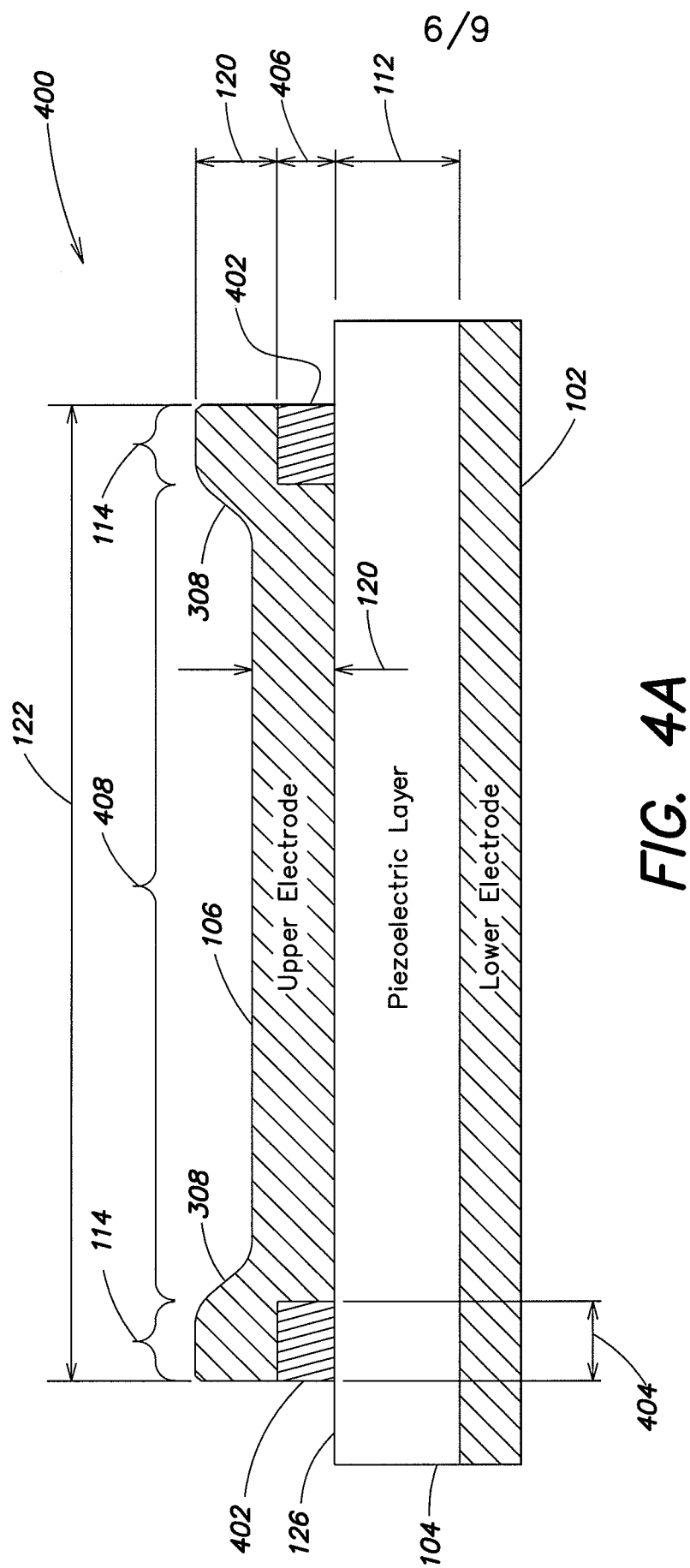
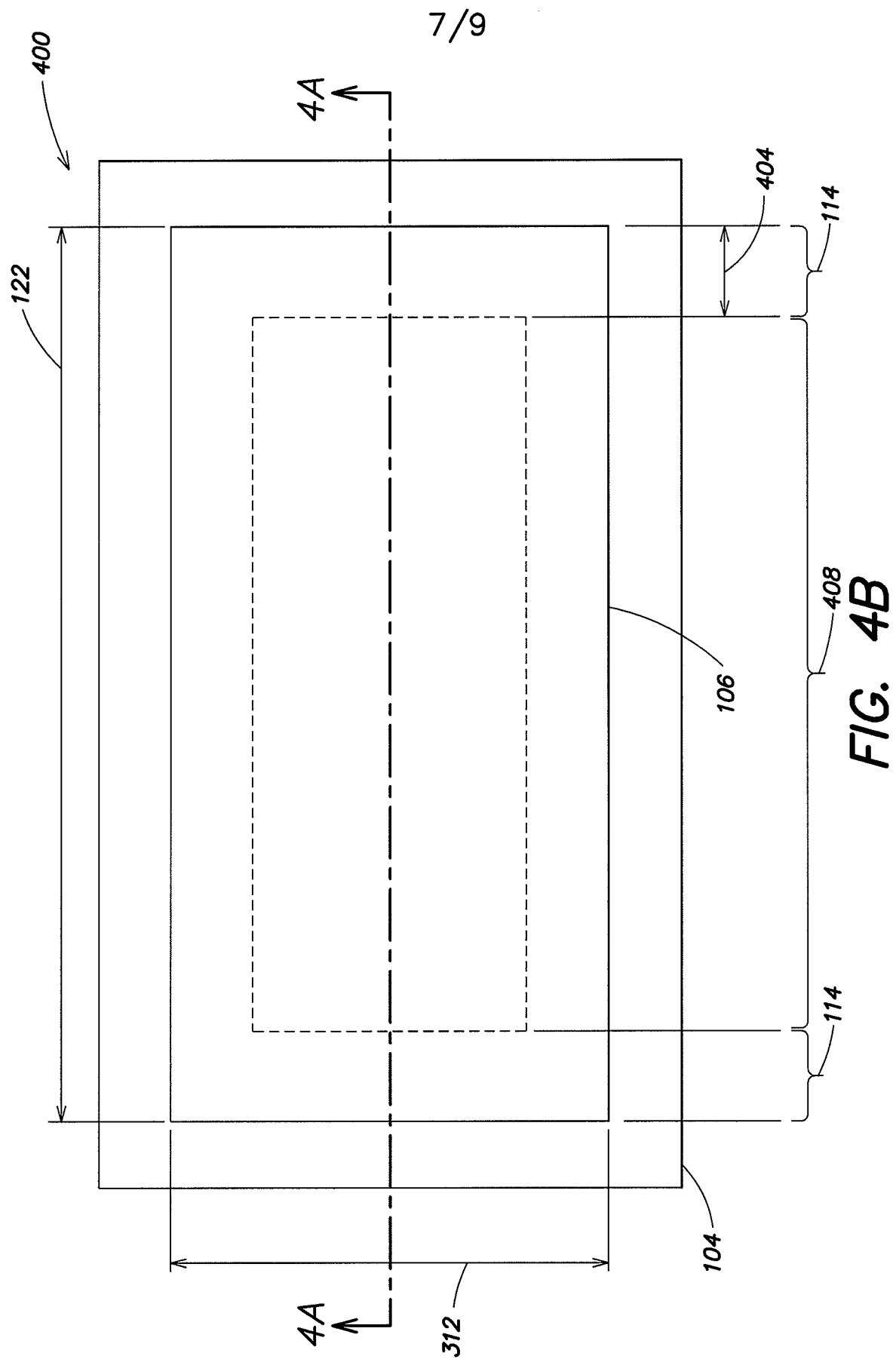
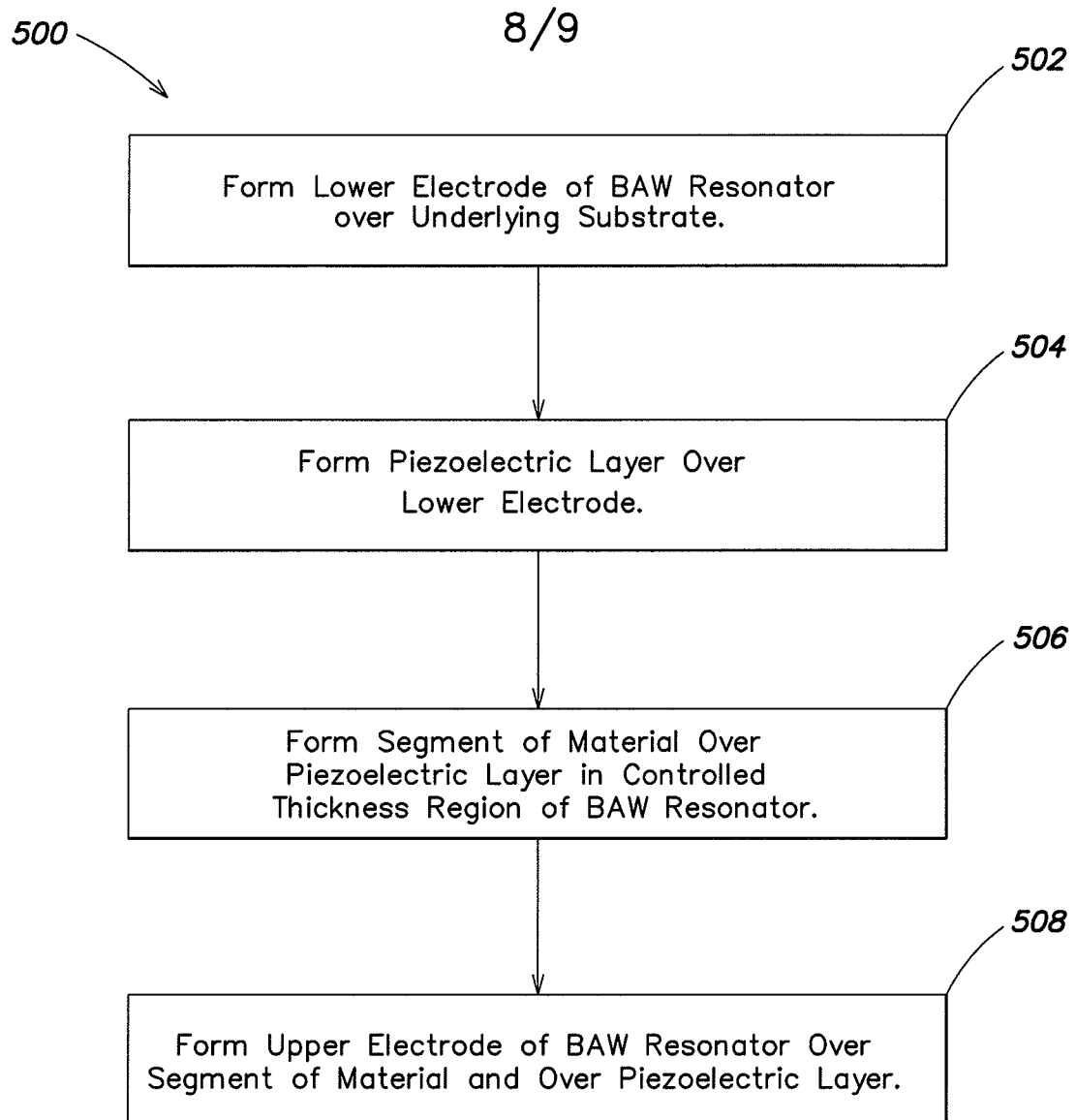
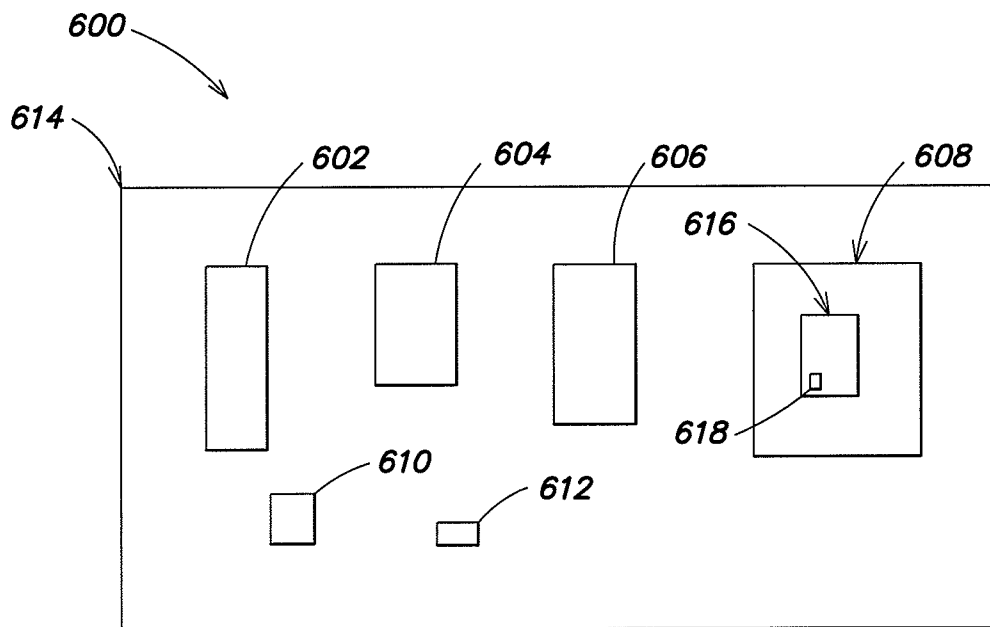


FIG. 4A



**FIG. 5**

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**FIG. 6**