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Lee

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(54) **METHOD FOR FABRICATING FILM BULK ACOUSTIC RESONATOR (FBAR) DEVICE**

(75) Inventor: **Joo Ho Lee**, Kyungki-do (KR)

(73) Assignee: **Samsung Electro-Mechanics Co., LTD**, Kyungki-Do (KR)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
B05D 5/12 (2006.01)
H04R 17/00 (2006.01)

(52) **U.S. Cl.** **427/58**; 427/100; 29/25.35

(58) **Field of Classification Search** 427/58, 427/100, 402; 310/312, 346; 29/25.35; 333/189; 438/48, 50
See application file for complete search history.

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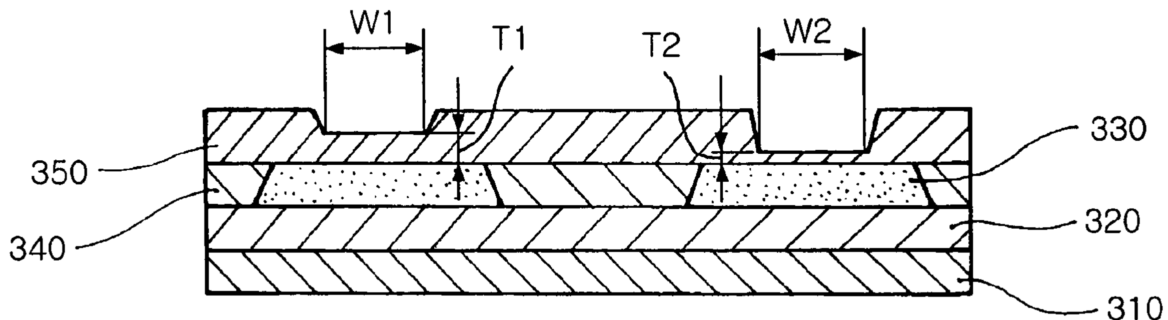
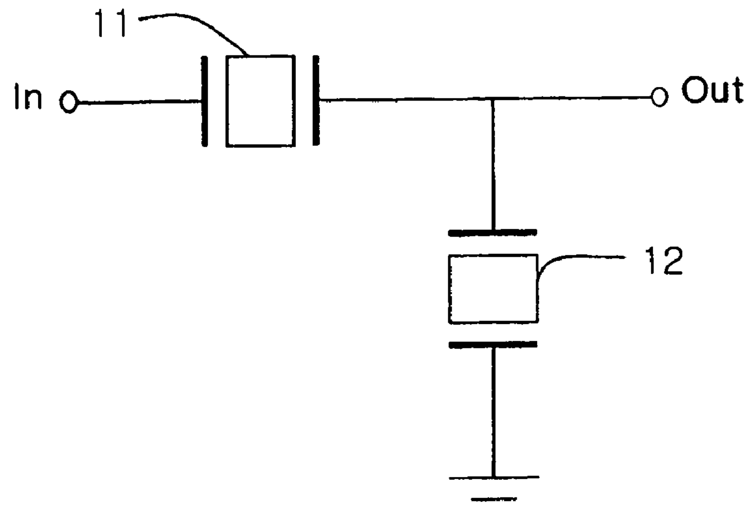
Primary Examiner—Brian K. Talbot
(74) *Attorney, Agent, or Firm*—Lowe Hauptman & Berner, LLP.

(57) **ABSTRACT**

A method for fabricating an FBAR device includes (a) preparing a substrate; (b) forming an insulating layer on the substrate; (c) forming a sacrificial layer on the insulating layer; (d) forming a plurality of sacrificial regions for forming air-gaps by selectively removing the sacrificial layer; (e) forming a membrane support layer on the insulating layer with the selectively removed sacrificial layer; (f) forming a membrane layer on the sacrificial regions and the membrane support layer; (g) forming a plurality of active regions on the sacrificial regions of the membrane layer so that a thickness of the active region corresponding to a series resonator differs from a thickness of the active region corresponding to a shunt resonator of the FBAR; (h) forming lower electrodes on the membrane layer including the active regions; (i) forming a piezoelectric layer on the lower electrodes; (j) forming upper electrodes on the piezoelectric layer; and (k) forming the air-gaps by removing the sacrificial regions.

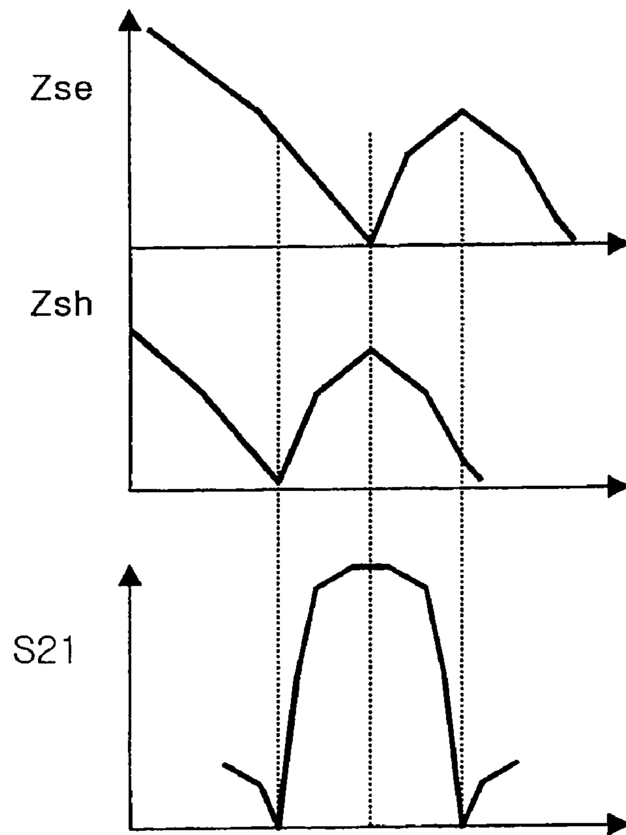
9 Claims, 9 Drawing Sheets





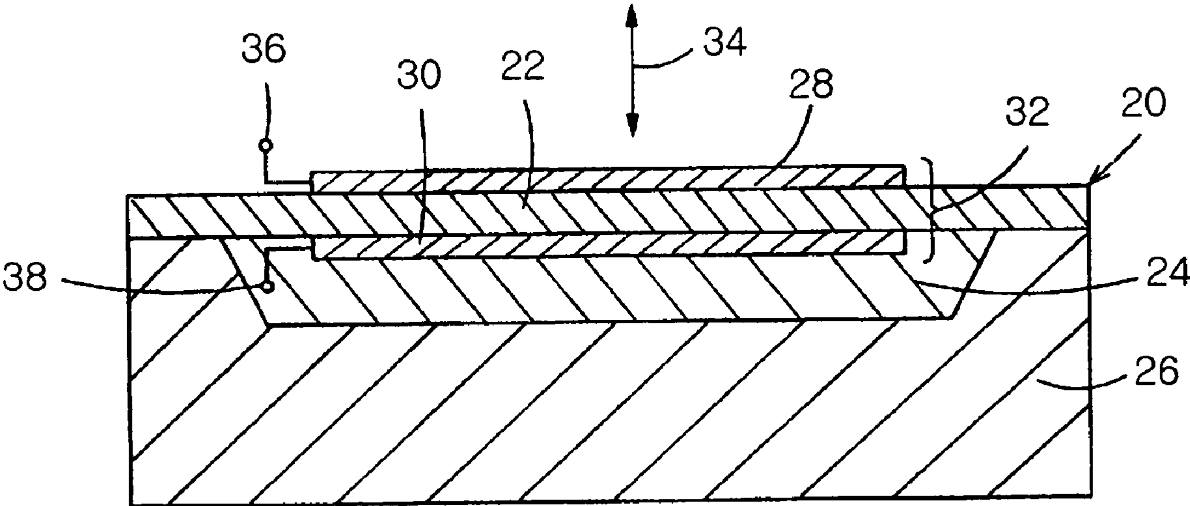
PRIOR ART

FIG. 1a



PRIOR ART

FIG. 1b



PRIOR ART

FIG. 2

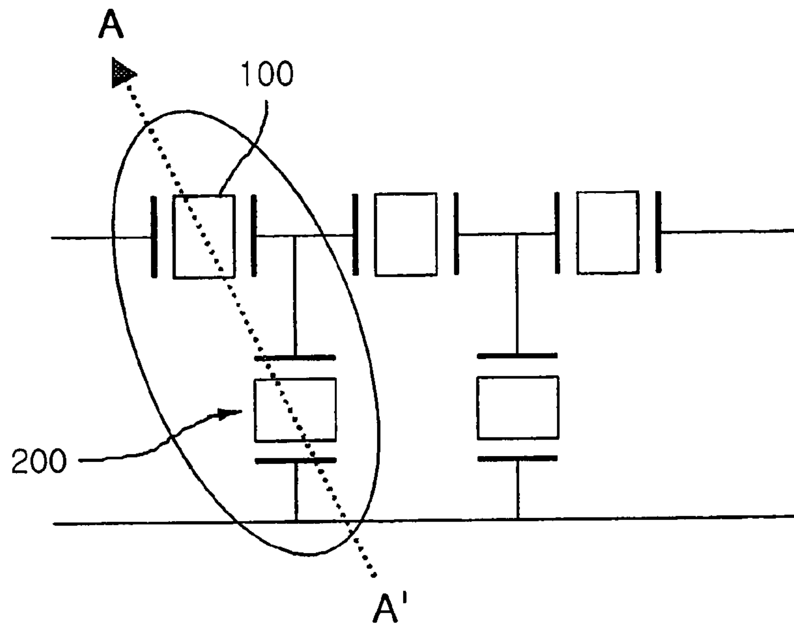


FIG. 3a

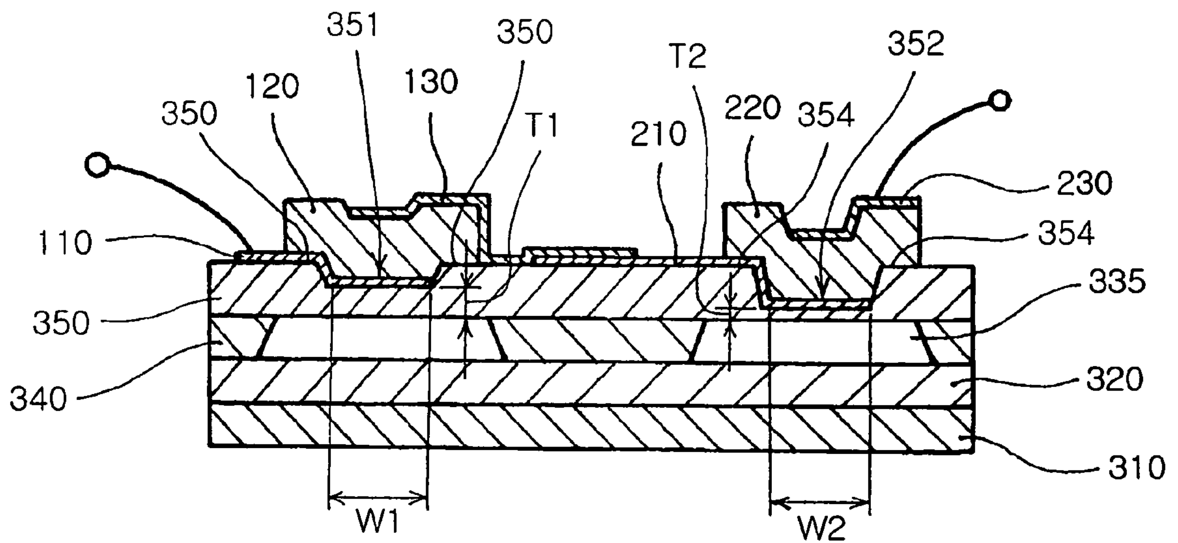


FIG. 3b

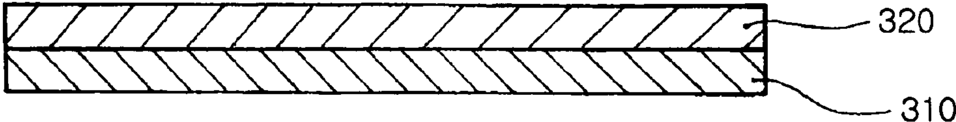


FIG. 4a

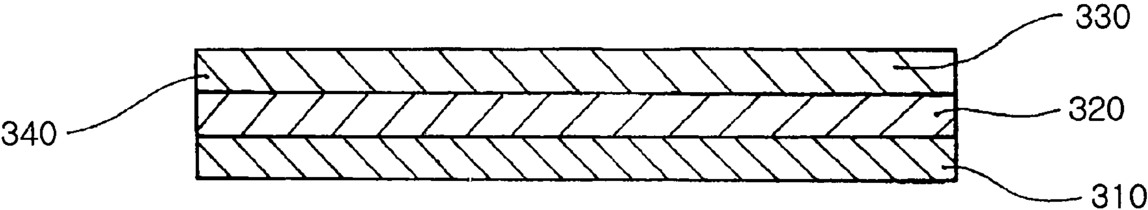


FIG. 4b

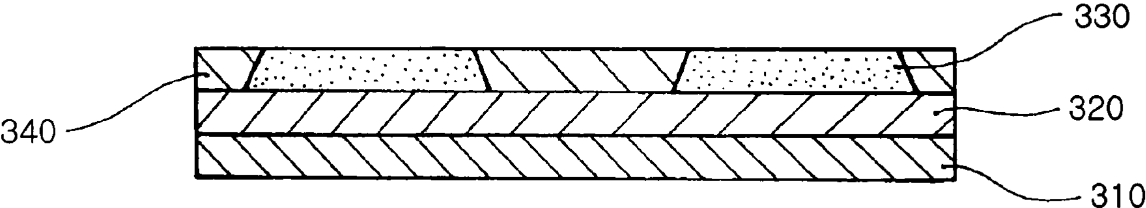


FIG. 4c

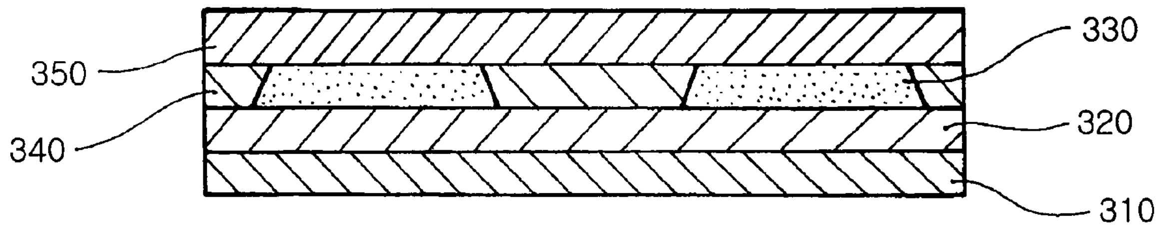


FIG. 4d

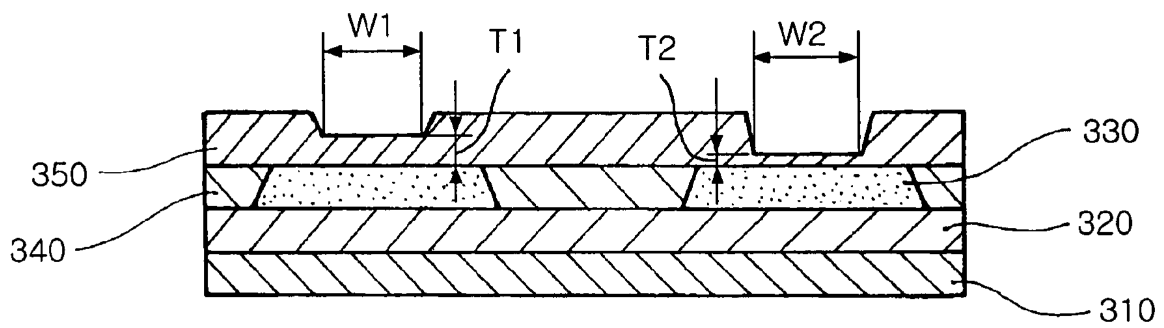


FIG. 4e

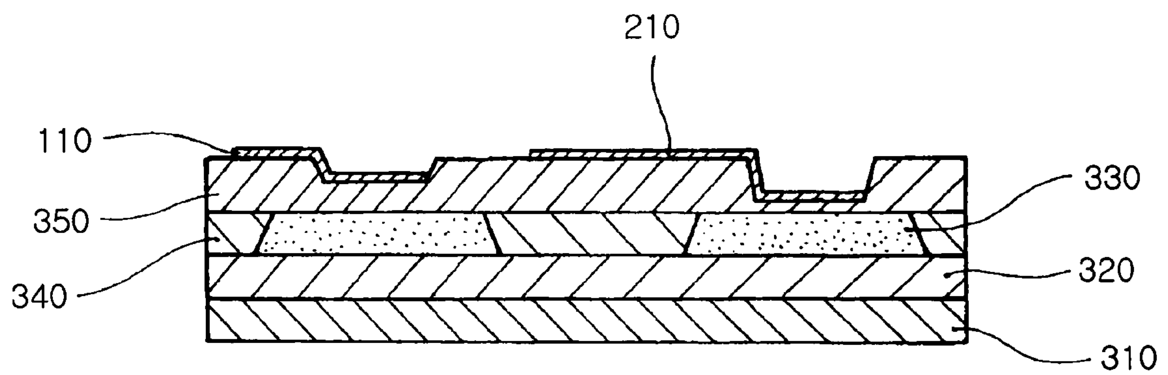


FIG. 4f

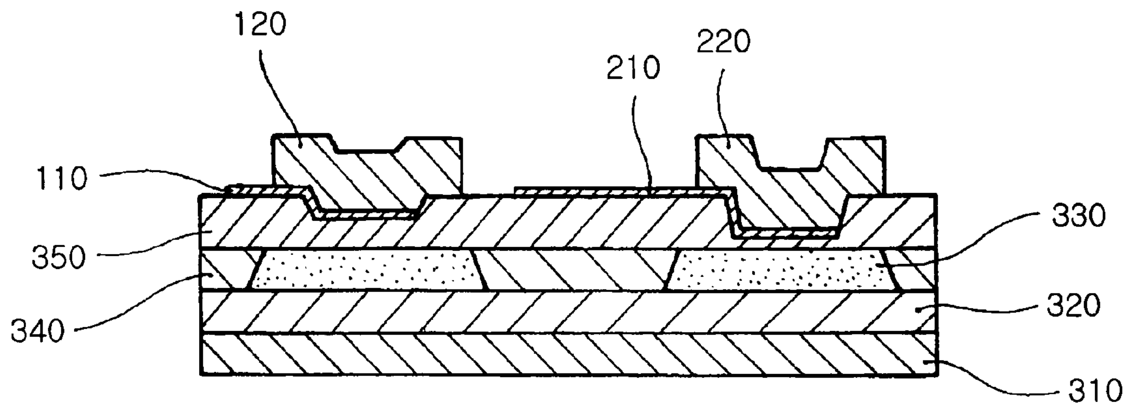


FIG. 4g

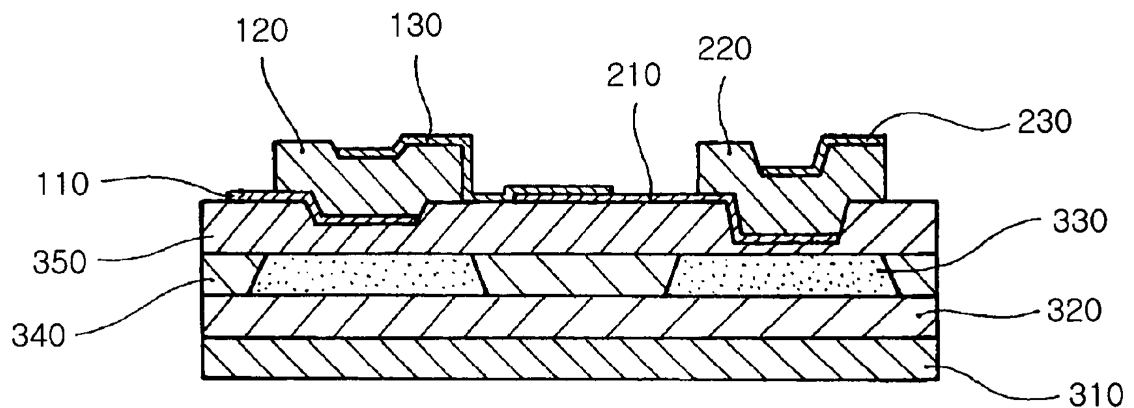


FIG. 4h

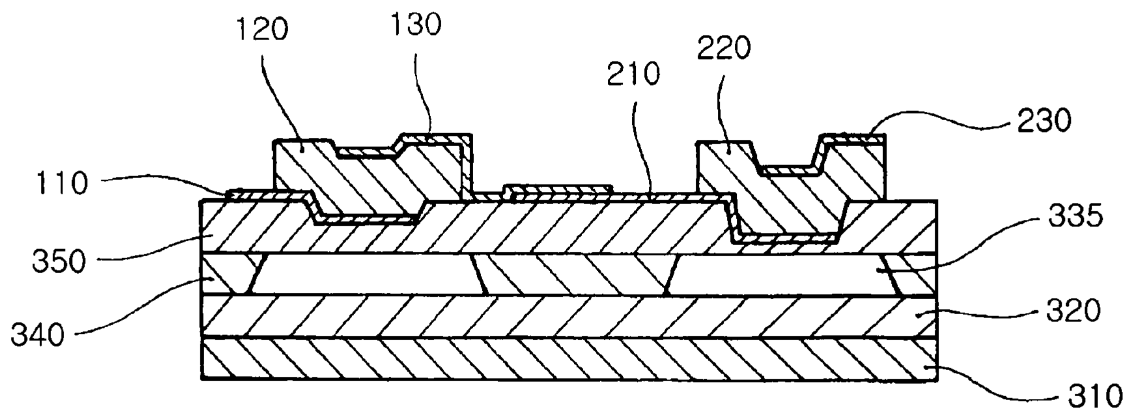


FIG. 4i

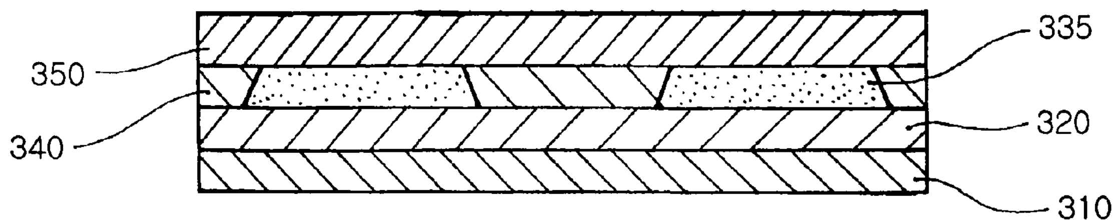


FIG. 5a

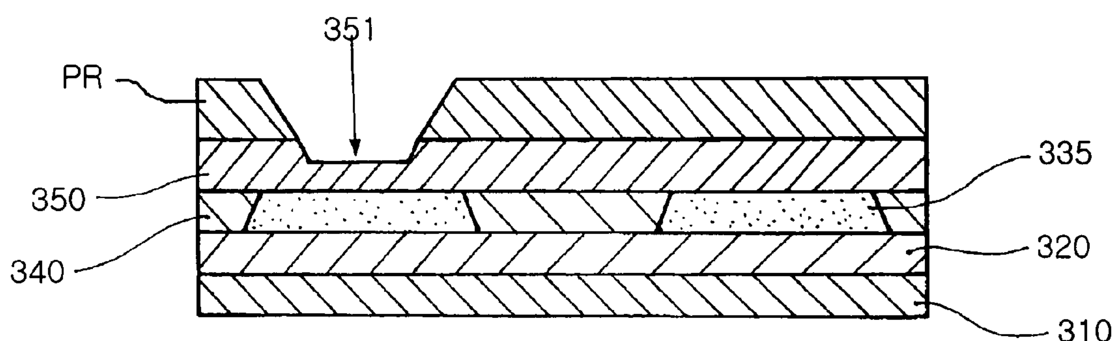


FIG. 5b

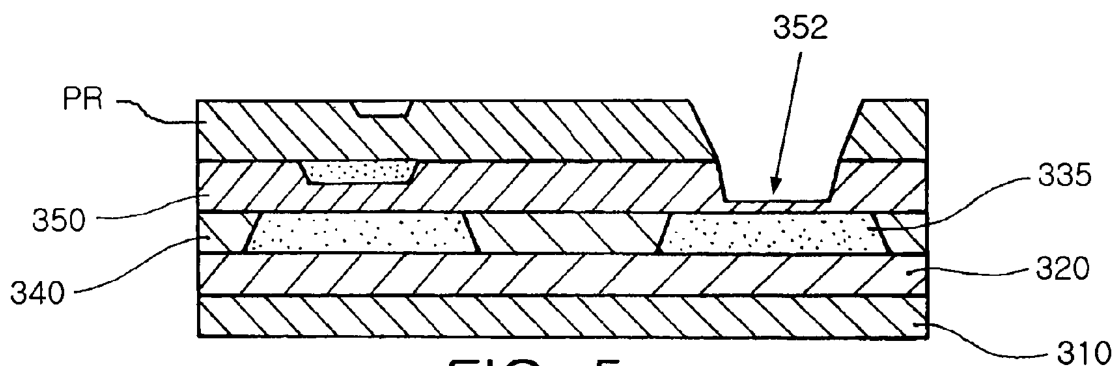


FIG. 5c

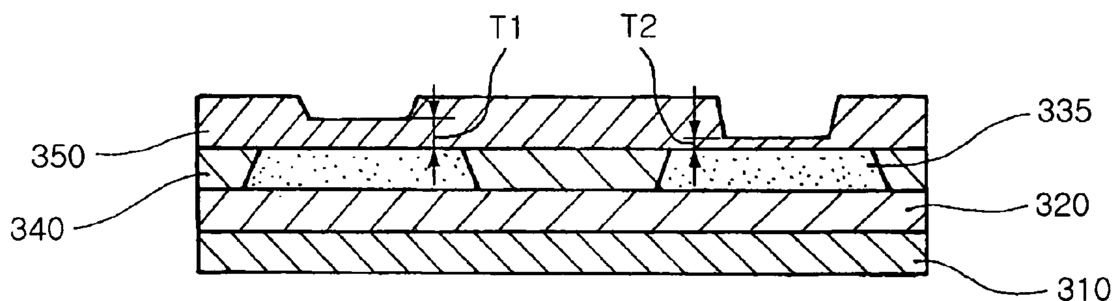


FIG. 5d

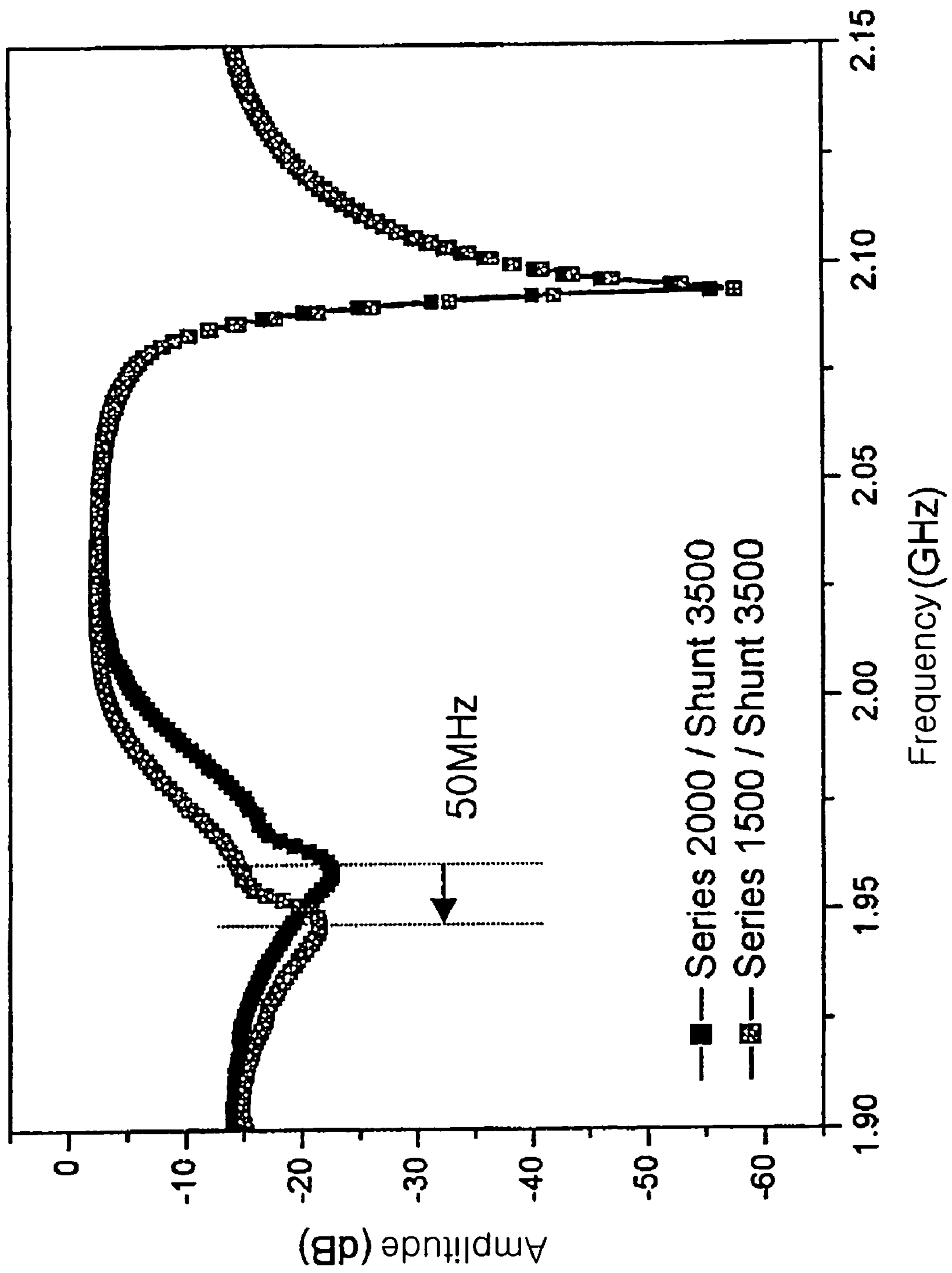


FIG. 6

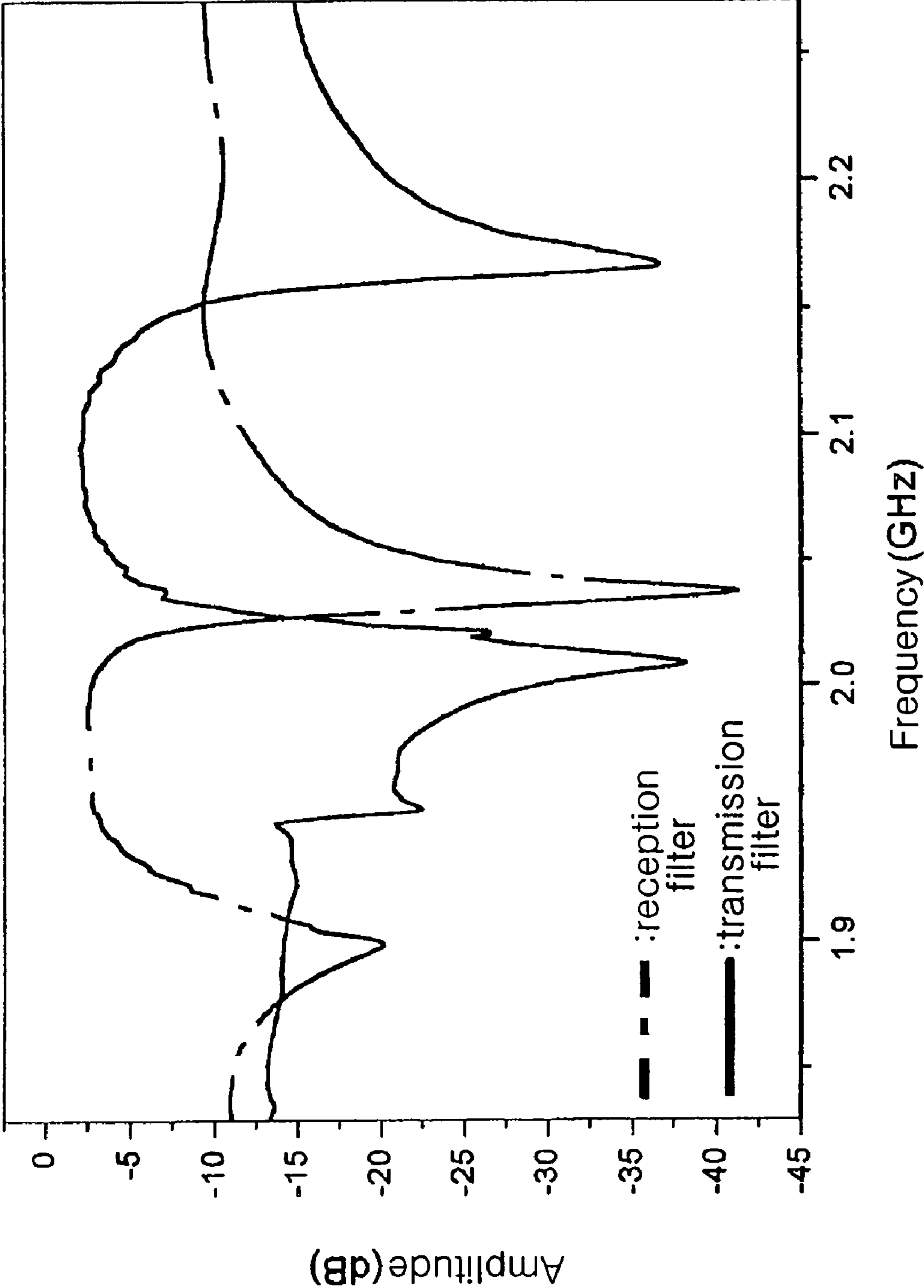


FIG. 7

METHOD FOR FABRICATING FILM BULK ACOUSTIC RESONATOR (FBAR) DEVICE

This application is a divisional of U.S. patent application Ser. No. 10/327,929 filed Dec. 26, 2002 now U.S. Pat. No. 6,842,089.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a film bulk acoustic resonator (FBAR) device and a method for fabricating the film bulk acoustic resonator (FBAR) device, and more particularly to a film bulk acoustic resonator (FBAR) device which comprises a membrane layer having a plurality of active regions and provides different resonant frequencies by providing different thicknesses of the active regions of series resonators and shunt resonators and by controlling the thicknesses, respectively, and a method for fabricating the film bulk acoustic resonator (FBAR) device.

2. Description of the Related Art

Recently, components for a mobile communication terminal such as radio frequency (RF) components have been developed to satisfy the trends of miniaturization and high-functionality of mobile communication terminals. Among the radio frequency (RF) components for mobile communication terminals, a filter is an essential component and serves to select a desired signal from many sky waves or to filter specific signals.

Particularly, as usable frequency bands of the mobile communication terminal increase, super high frequency (SHF) devices are required more and more. However, with the super high frequency (SHF) devices, it is difficult to satisfy the miniaturization and the low-cost trend required in mobile communication terminals. For example, a resonator or a filter which is operated at a frequency of more than 1 GHz has a large size, thereby not being integrated. Further, a dielectric resonator is replaced with a crystal resonator or a surface acoustic resonator. However, the crystal resonator and the surface acoustic resonator increase an insertion loss and cannot accomplish integration, miniaturization, and low cost.

In order to solve the aforementioned problems, a film bulk acoustic wave resonator ("FBAR", or may be referred to as a thin film resonator "TFR") using the resonance of a piezoelectric layer, has been developed and is now practically used.

Conventionally, the film bulk acoustic wave resonator (FBAR) device is a thin film type device, in which a thin film made of piezoelectric material such as ZnO or AlN is formed on a semiconductor substrate made of silicon or GaAs, thereby inducing resonance by piezoelectricity of the thin film. The film bulk acoustic wave resonator (FBAR) device is low-priced, miniaturized, and has a high quality. The film bulk acoustic wave resonator (FBAR) device can be used in radio communication equipment at various frequency bands (900 MHz~10 GHz) and military radar. Further, the film bulk acoustic wave resonator (FBAR) device can be micro-miniaturized to have a size less than one hundredth of that of a dielectric filter or a lumped constant (LC) filter, and has an insertion loss less than that of a surface acoustic wave device.

FIG. **1***a* is a circuit diagram of a conventional film bulk acoustic resonator (FBAR) device for a thin film filter, and FIG. **1***b* is a graph of the conventional film bulk acoustic resonator (FBAR) device for the thin film filter. FIG. **1***a* shows the ladder type conventional film bulk acoustic resonator (FBAR) device comprising a series resonator **11** and a shunt resonator **12** connected to the series resonator **11**. That is, a film bulk acoustic resonator (FBAR) filter is fabricated by the composition of the series resonator **11** and the shunt resonator **12**. Herein, different resonant frequencies of the series resonator **11** and the shunt resonator **12** are determined by the total thickness of a stack structure of the resonator including a piezoelectric layer. The difference of center frequencies between the series resonator **11** and the shunt resonator **12** is obtained by the difference of thicknesses of upper surfaces of the series resonator **11** and the shunt resonator **12**. Herein, the stack structure of the resonator determines the resonant frequency of the resonator, and usually comprises a lower electrode, the piezoelectric layer, and an upper electrode.

That is, the film bulk acoustic resonator (FBAR) device resonates due to the coupling between mechanical stress and load on the piezoelectric layer. The resonant frequency has a length of half an acoustic wave progressing within the device having the same thickness of the stack structure of the resonator comprising the piezoelectric layer and the electrodes. Therefore, the resonant frequency is determined by the total thickness of several layers of the stack structure of the resonator comprising the lower electrode, the piezoelectric layer, and the upper electrode.

The aforementioned film bulk acoustic resonator (FBAR) filter is shaped in a ladder type. The ladder type film bulk acoustic resonator (FBAR) filter is disclosed by "Thin Film Bulk Acoustic Wave Filters for GPS by K. M. Lakin et al. (Lakin), IEEE Ultrasonic Symposium, 1992, pp. 471–476". According to this paper, the ladder type film bulk acoustic resonator (FBAR) filter is formed by the composition of the series resonator and the shunt resonator. Each of the series resonator and the shunt resonator has a different center frequency.

Further, the film bulk acoustic resonator (FBAR) device comprises the lower electrode, the piezoelectric layer, and the upper electrode, which are formed on the silicon substrate in order. Herein, an electric field is applied to the upper and the lower electrode, and then a bulk acoustic wave is generated on the piezoelectric layer. In order to maintain the high quality (high-Q), the bulk acoustic wave must be prevented from affecting the silicon substrate. Therefore, in order to prevent the bulk acoustic wave from affecting the silicon substrate, a structure for separating the piezoelectric layer from the silicon substrate is required. Electrical characteristics the film bulk acoustic resonator (FBAR) device such as an insertion loss and a transducer gain, and a practical use of the film bulk acoustic resonator (FBAR) device depend on the aforementioned separation structure. The separation structure is mostly divided into a reflecting layer structure using Bragg reflection and an air-gap structure. The reflecting layer structure is very complicated and takes long time to manufacture. Further, compared to the air-gap structure, the reflecting layer structure deteriorates an insertion loss and reflective characteristics and reduces effective bandwidth. Therefore, the air-gap structure has been used now.

FIG. **2** is a cross-sectional view of the conventional film bulk acoustic resonator (FBAR) device. With reference to FIG. **2**, the conventional film bulk acoustic resonator (FBAR) device **20** comprises a piezoelectric layer **22**, which is supported by an outer circumference of a well **24** formed on an upper surface of a substrate **26**. An upper electrode **28** and a lower electrode **30** are formed on the upper and lower surfaces of the piezoelectric layer **22**. The upper electrode **38** and the lower electrode **30** correspond to the well **24**. The

electrical connection between the upper electrode **38** and the lower electrode **30** is accomplished by an upper terminal **36** and a lower terminal **38**. A stack structure **32** of the conventional film bulk acoustic resonator (FBAR) device **20** is formed by the piezoelectric layer **20**, the upper electrode **28** and the lower electrode **30**. Herein, the stack structure **32** of the film bulk acoustic resonator (FBAR) device **20** expands or contracts in the direction of the arrow **34** according to a direction and a level of a voltage provided between two electrodes **28** and **30**.

As described above, in the conventional film bulk acoustic resonator (FBAR) device **20**, a center frequency of the resonator depends on the total thickness of the stack structure **32** comprising the piezoelectric layer **20**, the upper electrode **28** and the lower electrode **30**. Therefore, in order to provide different center frequencies, the thickness of the upper electrode **28** or the lower electrode **30**, or the thickness of the piezoelectric layer **20**, must be adjusted.

Further, it is difficult to finely control the resonant frequency by the adjustment of the thicknesses of the electrodes or the piezoelectric layer. Moreover, it is not easy to simultaneously manufacture a transmission filter and a reception filter on the same substrate.

SUMMARY OF THE INVENTION

Therefore, the present invention has been made in view of the above problems, and it is an object of the present invention to provide a film bulk acoustic resonator (FBAR) device which comprises a membrane layer having a plurality of active regions and provides different resonant frequencies by providing different thicknesses of the active regions according to series resonators and shunt resonators from each other and by controlling the thicknesses.

It is another object of the present invention to provide a method for fabricating a film bulk acoustic resonator (FBAR) device having a stable structure and excellent characteristics. In this method, a plurality of the film bulk acoustic resonator (FBAR) devices having different resonant frequencies are manufactured on a single substrate, thereby simultaneously manufacturing a transmission filter and a reception filter on the same substrate.

In accordance with one aspect of the present invention, the above and other objects can be accomplished by the provision of a film bulk acoustic resonator (FBAR) device, which is applied to a ladder type filter comprising a plurality of series resonators and a plurality of shunt resonators, comprising: a substrate; an insulating layer formed on the substrate; a membrane support layer being formed on the insulating layer and comprising a plurality of air-gaps; a membrane layer being formed on the membrane support layer and comprising a plurality of active regions to correspond to the air-gaps; a plurality of lower electrodes, each being formed on the active region; a plurality of piezoelectric layers, each being formed on the lower electrode; and a plurality of upper electrodes, each being formed on the piezoelectric layer, wherein a thickness of the active region corresponding to the series resonator differs from a thickness of the active region corresponding to the shunt resonator.

In accordance with another aspect of the present invention, there is provided a film bulk acoustic resonator (FBAR) device, which is applied to a ladder type filter comprising a plurality of series resonators and a plurality of shunt resonators, comprising: a substrate; an insulating layer formed on the substrate; a membrane support layer being formed on the insulating layer and comprising a plurality of air-gaps; a membrane layer being formed on the membrane support layer and comprising a plurality of active regions to correspond to the air-gaps; a plurality of lower electrodes, each being formed on the active region; a plurality of piezoelectric layers, each being formed on the lower electrode; and a plurality of upper electrodes, each being formed on the piezoelectric layer, wherein a thickness of the active region corresponding to the series resonator differs from a thickness of the active region corresponding to the shunt resonator, and center frequencies of the series resonators and the shunt resonators are controlled by adjusting the thicknesses of the active regions of the membrane layer.

In accordance with yet another aspect of the present invention, there is provided a method for fabricating a film bulk acoustic resonator (FBAR) device, which is applied to a ladder type filter comprising a plurality of series resonators and a plurality of shunt resonators, comprising the steps of: (a) preparing a substrate; (b) forming an insulating layer on the substrate; (c) forming a sacrificial layer on the insulating layer; (d) forming a plurality of sacrificial regions for forming air-gaps by selectively removing the sacrificial layer; (e) forming a membrane support layer on the insulating layer with the selectively removed sacrificial layer; (f) forming a membrane layer on the sacrificial regions and the membrane support layer; (g) forming a plurality of active regions on the sacrificial regions of the membrane layer so that a thickness of the active region corresponding to the series resonator differs from a thickness of the active region corresponding to the shunt resonator; (h) forming lower electrodes on the membrane layer including the active regions; (i) forming an piezoelectric layer on the lower electrodes; (j) forming upper electrodes on the piezoelectric layer; and (k) forming the air-gaps by removing the sacrificial regions.

Preferably, in the step (g), the active regions of the membrane layer may be formed in designated thicknesses by etching parts of the membrane layer corresponding to the sacrificial regions.

Further, preferably, the thicknesses of the active regions of the membrane layer may be the same as or less than those of other regions of the membrane layer. Herein, center frequencies of the series resonators and the shunt resonators may be controlled by adjusting the thicknesses of the active regions of the membrane layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. **1***a* is a circuit diagram of a conventional film bulk acoustic resonator (FBAR) device for a thin film filter;

FIG. **1***b* is a graph of the conventional film bulk acoustic resonator (FBAR) device for the thin film filter;

FIG. **2** is a cross-sectional view of the conventional film bulk acoustic resonator (FBAR) device;

FIG. **3***a* is a circuit diagram of a filter employing a film bulk acoustic resonator (FBAR) device in accordance with the present invention;

FIG. **3***b* is a cross-sectional view taken along the line A–A' of the filter of FIG. **3***a;*

FIGS. **4***a* through **4***i* are cross-sectional views illustrating a method for fabricating the film bulk acoustic resonator (FBAR) device in accordance with the present invention;

FIGS. **5***a* through **5***d* are cross-sectional view showing an etching step of an active region of a membrane layer of FIG. **4***d;*

FIG. **6** is a graph showing frequency response of the film bulk acoustic resonator (FBAR) device in accordance with the present invention; and

FIG. **7** is a graph showing frequency response of a transmission filter and a reception filter employing the film bulk acoustic resonator (FBAR) device in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings.

FIG. **3***a* is a circuit diagram of a filter employing a film bulk acoustic resonator (FBAR) device in accordance with the present invention. FIG. **3***b* is a cross-sectional view taken along the line A–A' of the filter of FIG. **3***a*.

With reference to FIG. **3***a*, the film bulk acoustic resonator (FBAR) of the present invention is employed to a ladder type filter, and comprises a plurality of series resonators **100**, which are serially connected to each other, and a plurality of shunt resonators **200**, which are disposed between the series resonators **100** and grounded. Herein, the FBAR of the present invention is operated as the series resonators **100** or the shunt resonators **200**. A filter is embodied by a combination of the series resonators **100** and the shunt resonators **200**.

FIG. **3***b* is a cross-sectional view taken along the line A–A' of the filter of FIG. **3***a* comprising a pair of one series resonator **100** and one shunt resonator **200**. With reference to FIG. **3***b*, the film bulk acoustic resonator (FBAR) of the present invention comprises a substrate **310**, an insulating layer **320**, a membrane support layer **340**, membrane layer **350**, a plurality of lower electrodes **110** and **210**, a plurality of piezoelectric layers **120** and **220**, and a plurality of upper electrodes **130** and **230**. The insulating layer **320** is formed on the substrate **310**. The membrane support layer **340** is formed on the insulating layer **320** and comprises a plurality of air-gaps **335**. The membrane layer **350** is formed on the membrane support layer **340** and comprises a plurality of active regions. The active regions of the membrane layer **350** correspond to the air gaps **335** of the membrane support layer **340**. The lower electrodes **110** and **210** are formed on the active regions of the membrane layer **350**. The piezoelectric layers **120** and **220** are formed on the lower electrodes **110** and **210**. The upper electrodes **130** and **230** are formed on the piezoelectric layers **120** and **220**.

In order to effectively provide center frequency by comprising the membrane layer **350**, the thicknesses Ti and T**2** of the active regions of the membrane layer **350** are preferably thinner than that of other regions of the membrane layer **350**. More particularly, the thicknesses T**1** and T**2** of the active regions of the membrane layer **350** is less than 50% of that of other regions of the membrane layer **350**. Most preferably, the thicknesses T**1** and T**2** of the active regions of the membrane layer **350** are in a range of 0.01–1.0 μm.

Particularly, in order to provide different center frequencies of each of the series resonator and the shunt resonator of the film bulk acoustic resonator (FBAR) of the present invention from each other, the thickness T**1** of the active region of the membrane layer, which corresponds to the series resonator, and the thickness T**2** of the active region of the membrane layer, which corresponds to the shunt resonator, are differently designated.

The upper surface of the active regions of the membrane layer **350** may be subsided. This subsided upper surface of the active regions of the membrane layer **350** is formed by an etching process such as a wet etching or a dry etching.

The center frequencies of the series resonator **100** and the shunt resonator **200** are controlled by adjusting the thicknesses of the active regions of the membrane layer **350**. As described above, the thickness T**1** of the active region of the membrane layer **350**, which corresponds to the series resonator **100** of FIG. **3***a*, and the thickness T**2** of the active region of the membrane layer **350**, which corresponds to the shunt resonator **200** of FIG. **3***a*, are different from each other. Thereby, the film bulk acoustic resonator (FBAR) filter is embodied by the series resonator **100** and the shunt resonator **200**, which provide different resonant frequencies.

In case that two FBAR filters are formed on the single substrate, and passband of each FBAR filter is used as a transmission frequency and a reception frequency band, a transmission filter and a reception filter are simultaneously formed on the same substrate.

Further, the present invention provides a method for manufacturing the film bulk acoustic resonator (FBAR) of the embodiment as shown in FIG. **3***b*. According to the method for manufacturing the film bulk acoustic resonator (FBAR) of the present invention, the thicknesses of the active regions corresponding to each of the series resonator and the shunt resonator are differently formed, thereby forming the filters on the single substrate. The center frequency of the resonator is easily controlled by adjusting the thicknesses of the active regions.

FIGS. **4***a* through **4***i* are cross-sectional views showing respective steps of a method for fabricating the film bulk acoustic resonator (FBAR) in accordance with the present invention. With reference to FIG. **4***a*, the silicon substrate **310** is prepared (step a), and then the insulating layer **320** is formed on the substrate **310** (step b). Herein, a thermal oxide, which is easily grown on the substrate **310**, may be used as the insulating layer **320**. Alternatively, an oxide or a nitride, which is formed by a conventional deposition technique such as chemical vapor deposition (CVD), may be optionally used as the insulating layer **320**.

FIGS. **4***b* to **4***d* show a process for forming sacrificial regions **330** for forming the air-gaps on the insulating layer **320** of the substrate **310**. With reference to FIG. **4***b*, a sacrificial layer **330** is formed entirely on the upper surface of the insulating layer **320** (step c). Herein, a material which has an excellent roughness and is easily formed and removed, e.g., polysilicon or ZnO is used as the sacrificial layer **330**. Then, the sacrificial layer **330** is selectively removed, thereby forming a plurality of the sacrificial regions for forming the air-gaps (step d). In this embodiment of the present invention, polysilicon is used as the sacrificial layer **330** as described above. The polysilicon has an excellent roughness and is easily formed and removed. Particularly, in subsequent steps, the sacrificial layer **330** made of polysilicon is selectively removed by a dry etching process.

As the dry etching of the sacrificial layer **330** is performed, a photoresist layer is coated on the upper surface of the sacrificial layer **330** to correspond to regions for the air-gap regions. The exposed regions of the sacrificial layer **330** from the photoresist layer are removed by the dry etching, thereby forming the sacrificial regions for the air-gaps regions. Then, the coated photoresist layer is removed, thereby completing sacrificial regions.

With reference to FIG. **4***c*, the membrane support layer **340** is formed on the upper surface of the insulating layer **320**, on which sacrificial regions are formed (step e). That is,

a photoresist layer is formed entirely on the substrate **310** with the sacrificial regions formed thereon, and insulating material is deposed entirely on the substrate **310**. Then, the photoresist is lifted off and removed, thereby forming the membrane support layer **340** as shown in FIG. **4***c*. Herein, the membrane support layer **340** is made of a material selected from the group consisting of SiO_2, SiN or Al_2O_3.

With reference to FIG. **4***d*, the membrane layer **350** is formed on the upper surfaces of the sacrificial regions and the membrane support layer **340** (step f). After forming the membrane support layer **340**, the membrane layer **350** is formed on the upper surfaces of the sacrificial regions and the membrane support layer **340**. Herein, the membrane layer **350** may be formed by depositing a SiO_2 layer in a thickness of 0.01–1.0 μm by CVD. Alternatively, the membrane layer 350 may be deposited by evaporating or sputtering. Further, an oxide such as Si3N4 or A1203, or a nitride may be used as the membrane layer **350**.

With reference to FIG. **4***e*, a plurality of the active regions are formed on the upper surface of the membrane layer **350** to correspond to the sacrificial regions (step g). Herein, among plural active regions, the thickness of the active region corresponding to the series resonator of the filter and the thickness of the active region corresponding to the shunt resonator of the filter are different from each other. That is, after forming the membrane layer **350**, the regions of the membrane layer **350** corresponding to the sacrificial regions are etched, thereby forming the active regions of the membrane layer **350** so as to have designated thicknesses.

Preferably, the thicknesses of the active regions of the membrane layer **350** are the same as or thinner than that of other regions of the membrane layer **350**. The upper surfaces of the active regions are subsided by etching.

FIGS. **5***a* through **5***c* are cross-sectional views showing the etching of the active regions of the membrane layer of FIG. **4***d*. With reference to FIGS. **5***a* and **5***b*, the membrane layer **350** is selectively dry-etched, thereby forming active regions having a thickness of 0.0–1.0 μm. Then, a photoresist (PR) is formed entirely on the substrate **310**. As shown in FIG. **5***d*, the membrane layer **350** is selectively dry-etched, thereby forming active regions of the membrane layer **350** of the series resonator and the shunt resonator. The thicknesses T**1** and T**2** of the active regions of the membrane layer **350** of the series resonator and the shunt resonator may be different from each other by PR deposition and PR removal steps.

For example, the photoresist (PR) is deposited entirely on the substrate **310**. Then the substrate **310** deposited with the photoresist (PR) is hard-baked using a hot plate for 1–20 min at the temperature of 110–200° C. Then, CF_4 gas of 10–100 sccm is introduced into the substrate **310**, and the substrate **301** is etched for 10–1,000 sec using a reactive ion etching (RIE) equipment. The thicknesses T**1** and T**2** of the active regions of the membrane layer **350** of the series resonator and the shunt resonator are determined by a kind of the etching equipment, a kind of the etchant, an etching rate, and etching time. Thereby, the thickness of the active region is controlled to a desired level by properly adjusting the kind of the etching equipment, the kind of the etchant, the etching rate, and the etching time. The center frequencies of the series resonator and the shunt resonator may be controlled by adjusting the thicknesses of the active regions of the membrane layer.

The active regions of the membrane layer may be etched by reflective ion etching (RIE), inductively coupled plasma (ICP), or electron cyclotron resonance (ECR) equipments using a single gas of CxFy, SF_6, Cl_2, CCl_2F_2, XeF_2, BrF_2, H_2, O_2, or a composition thereof.

The center frequencies of each of the series resonator and the shunt resonator of the film bulk acoustic resonator (FBAR) of the present invention are controlled by differently forming the thicknesses of the active regions of the membrane layer corresponding to the series resonator and the shunt resonator by the etching process. Herein, the center frequency of each of the series resonator and the shunt resonator is determined by total thickness of the resonator stack structure comprising the lower electrodes, the piezoelectric layers, the upper electrodes and the active regions of the membrane layer.

As shown in FIG. **5***d*, each thickness T**1** and T**2** of the active regions of the membrane layer of the resonator stack structure comprising the upper and lower electrodes and the piezoelectric layers are differently formed in a range of 0.0–1.0 μm, thereby being capable of fabricating the series resonator and the shunt resonator, having different resonant frequencies. That is, the center frequencies of the series resonator and the shunt resonator may be controlled by a simple fabricating process. Further, a film bulk acoustic resonator (FBAR) filter having a more firm and stable structure can be fabricated by comprising the membrane layer.

With reference to FIGS. **4***f* to **4***h*, the lower electrodes **110** and **210** are formed on the membrane layer **350** including the active regions (step h), and the piezoelectric layers **120** and **220** are formed on the lower electrodes **110** and **210** (step i). Then, the upper electrode **130** and **230** are formed on the piezoelectric layers **120** and **220** (step j).

Herein, material with an excellent conductivity such as Ta, Al, W, Au, Mo, Pt, Ru, or Ti, or a composition layer thereof such as Ta/Au/Mo, Ti/Au/Mo, Ti/Au, Ti/Pi, Ti/W, Ta/W, Cr/W, Ta/Pt, or Ta/Al may be used as the lower electrodes **110** and **120** and the upper electrodes **130** and **230**. Further, material with an excellent piezoelectricity such as AIN, PZT including ZnO may be used as the piezoelectric layers **120** and **220**.

The center frequency of each filter is controlled using a difference in thicknesses of the upper electrodes **130** and **230** deposited on the piezoelectric layers **120** and **220**. Therefore, a filter, which is operated in a wide frequency range of about 100 MHz of a transmission port and a reception port required in manufacturing a duplexer, is fabricated on a single substrate by using a difference between the thicknesses T**1** and T**2** obtained by etching the active regions of the membrane layer and the thicknesses of the upper electrodes **130** and **230** deposited on the piezoelectric layers **120** and **220**.

With reference to FIG. **4***i*, the air-gaps **335** are formed by removing the sacrificial regions (step k). Herein, the sacrificial regions of the sacrificial layer **330** are removed by the wet etching and the dry etching process. The etching type is determined by the material of the sacrificial layer **330**. For example, via holes for interconnecting the sacrificial layer **330** to the outside are formed, and an etchant is provided to the sacrificial layer **330** through the via holes. The etchant for removing the sacrificial layer **330** may also etch the piezoelectric layers **120** and **220**. Further, the via holes are formed outside the perimeter of the active regions. As described above, after forming the via holes, the sacrificial regions are removed through the via holes, thereby forming the air-gaps **335**.

FIG. **6** is a graph showing frequency response of the film bulk acoustic resonator (FBAR) in accordance with the present invention. As shown in FIG. **6**, when the thickness

of the membrane layer of the film bulk acoustic resonator (FBAR) of the present invention is changed by 100 Å, its resonant frequency is changed by 10 MHz, and when the thickness of the upper electrode of the film bulk acoustic resonator (FBAR) of the present invention is changed by 100 Å, its resonant frequency is changed by 18 MHz. Thereby, the frequency is easily controlled by adjusting the thickness of the membrane layer with less sensitivity rather than the thickness of the upper electrode.

Further, with the film bulk acoustic resonator (FBAR) of the present invention, the transmission filter and the reception filter may be formed on the same substrate. In this case, when the thickness of the membrane layer, the thickness of the lower electrode, the thickness of the piezoelectric layer, and the thickness of the upper electrode are described in the following Table 1, frequency response characteristics as shown in FIG. **7** were obtained.

TABLE 1

unit [Å]

	Thickness of membrane layer		Thickness	Thickness of piezo-	Thickness
	Series resonator	Shunt resonator	of lower electrode	electric layer	of upper electrode
Transmission filter	1,500	3,500	1,000	10,300	3,300
Reception filter	1,500	3,500	1,000	10,300	2,100

FIG. **7** is a graph showing frequency response of the transmission filter and the reception filter employing the film bulk acoustic resonator (FBAR) in accordance with the present invention. With reference to FIG. **7**, the film bulk acoustic resonator (FBAR) of the present invention comprising the series resonator and the shunt resonator serves as a filter. The transmission filter and the reception filter may be formed on the same substrate by controlling the thicknesses of the active regions of the membrane layer.

As described above, the film bulk acoustic resonator (FBAR) device comprises a plurality of layers having different thicknesses. Resonant frequency is determined by the thickness of at least one layer out of plural layers. Differing from the conventional case using the difference of the thicknesses between the upper electrodes, the present invention differently etches the active regions of the series resonator and the shunt resonator of the filter, thereby being different thicknesses of the active regions. Therefore, the film bulk acoustic resonator (FBAR) filter can be fabricated by an economical and simple process and the center frequency and the filter can be effectively controlled.

As apparent from the above description, the present invention provides a film bulk acoustic resonator (FBAR) device comprising a membrane layer having a plurality of active regions. Each of the active regions corresponds to the series resonator and the shunt resonator. The thicknesses of the active regions corresponding to the series resonator and the shunt resonator differ from each other. Therefore, the film bulk acoustic resonator (FBAR) device provides different resonant frequencies by providing different thicknesses of the active regions of the series resonator and the shunt resonator, and by controlling the thicknesses, respectively. Thereby, a plurality of the film bulk acoustic resonator (FBAR) devices having different resonant frequencies can be manufactured, and a transmission filter and a reception filter can be simultaneously manufactured on the same substrate. Further, the film bulk acoustic resonator (FBAR) device of the present invention has a stable structure and excellent characteristics.

Moreover, a transmission filter and a reception filter, which are operated in a wide frequency range are fabricated on a single substrate by using the difference between the thicknesses of the etched active regions and the thickness of the upper electrode deposed on the piezoelectric layer. Therefore, the transmission filter and the reception filter, which were conventionally manufactured on different substrates, can be simultaneously manufactured on the same substrate, thereby manufacturing the transmission filter and the reception filter within one single chip.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.

What is claimed is:

1. A method of fabricating a film bulk acoustic resonator (FBAR) device, said device comprising a series resonator and a shunt resonator, said method comprising the steps of:

(a) preparing a substrate;

(b) forming an insulating layer on the substrate;

(c) forming a sacrificial layer on the insulating layer;

(d) forming a plurality of sacrificial regions by selectively removing the sacrificial layer;

(e) forming a membrane support layer on the insulating layer with the selectively removed sacrificial layer;

(f) forming a membrane layer on the sacrificial regions and the membrane support layer;

(g) forming a plurality of active regions in the membrane layer and on the sacrificial regions so that a thickness of the active region corresponding to the series resonator differs from a thickness of the active region corresponding to the shunt resonator;

(h) forming lower electrodes on the membrane layer including the active regions;

(i) forming an piezoelectric layer on the lower electrodes;

(j) forming upper electrodes on the piezoeleciric layer; and

(k) forming air-gaps by removing the sacrificial regions;

wherein the thicknesses of the active regions of the membrane layer are less than those of other regions of the membrane layer.

2. The method set forth in claim **1**, wherein the active regions of the membrane layer have subsided upper surfaces.

3. A method of fabricating a film bulk acoustic resonator (FBAR) device, said device comprising a series resonator and a shunt resonator, said method comprising the steps of:

(a) preparing a substrate;

(b) forming an insulating layer on the substrate;

(c) forming a sacrificial layer on the insulating layer;

(d) forming a plurality of sacrificial regions by selectively removing the sacrificial layer;

(e) forming a membrane support layer on the insulating layer with the selectively removed sacrificial layer;

(f) forming a membrane layer on the sacrificial regions and the membrane support layer;

(g) forming a plurality of active regions in the membrane layer and on the sacrificial regions by an etching process so that the thickness of the active region corresponding to the series resonator differs from the thickness of the active region corresponding to the shunt resonator;

(h) forming lower electrodes on the membrane layer including the active regions;
(i) forming an piezoelectric layer on the lower electrodes;
(j) forming upper electrodes on the piezoelectric layer; and
(k) forming air-gaps by removing the sacrificial regions, wherein center frequencies of the series resonator and the shunt resonator are controlled by adjusting the thicknesses of the active regions of the membrane layer in step (g).

4. A method of fabricating a film bulk acoustic resonator (FBAR) device, said device comprising a series resonator and a shunt resonator, said method comprising:

forming an insulating layer on top a substrate;
selectively forming sacrificial portions on top said insulating layer;
forming a membrane support layer on top the insulating layer and around said sacrificial portions;
forming a membrane layer on top both the sacrificial portions and the membrane support layer;
forming a photoresist layer on top of said membrane layer;
selectively etching both said photoresist layer and said membrane layer from active regions corresponding to the sacrificial portions;
completely removing said photoresist layer after said selectively etching;
forming lower electrodes on top the membrane layer including the active regions;
forming an piezoelectric layer on top the lower electrodes;
forming upper electrodes on top the piezoelectric layer; and
forming air-gaps by removing the sacrificial portions;
wherein the thickness of said membrane layer in the active region corresponding to the series resonator differs from the thickness of said membrane layer in the active region corresponding to the shunt resonator for controlling center frequencies of the series resonator and the shunt resonator.

5. The method of claim **4**, wherein the active region corresponding to the series resonator and the active region corresponding to the shunt resonator are formed by two different etching processes, and etching conditions of said two different etching processes are controlled to be different thereby facilitating control of the thicknesses of the active regions.

6. The method of claim **5**, comprising the following steps in the recited order:

(i) forming a first photoresist layer on top of said membrane layer;
(ii) selectively etching both said first photoresist layer and said membrane layer from the active region corresponding to the shunt resonator;
(iii) completely removing said first photoresist layer alter step (ii);
(iv) forming a second photoresist layer on top of said membrane layer, wherein said second photoresist layer covers the already formed active region corresponding to the shunt resonator;
(v) selectively etching both said second photoresist layer and said membrane layer from the active region corresponding to the series resonator; and
(vi) completely removing said second photoresist layer after step (v).

7. The method of claim **6**, wherein etching conditions of step (ii) and (v) are different from one another.

8. The method of claim **5**, comprising the following steps in the recited order:

(i) forming a first photoresist layer on top of said membrane layer;
(ii) selectively etching both said first photoresist layer and said membrane layer from the active region corresponding to the series resonator;
(iii) completely removing said first photoresist layer after step (ii);
(iv) forming a second photoresist layer on top of said membrane layer, wherein said second photoresist layer covers the already formed active region corresponding to the series resonator;
(v) selectively etching both said second photoresist layer and said membrane layer from the active region corresponding to the shunt resonator; and
(vi) completely removing said second photoresist layer after step (v).

9. The method of claim **8**, wherein etching conditions of step (ii) and (v) are different from one another.

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