REPUBLIC OF SOUTH AFRICA REPUBLIEK VAN SUID AFRIKA

PATENTS ACT, 1978

CERTIFICATE

n accordance with section 44 (1) of the Patents Act, No. 57 of 1978, it is hereby certified that:

Zhejiang University of Water Resources and Electric Power

Has been granted a patent in respect of an invention described and claimed in complete specification deposited at the Patent Office under the number

2022/07007

A copy of the complete specification is annexed, together with the relevant Form P2.

In te[illegible]y thereof, the seal of the Patent Office has been affixed at Pretoria with effect from the **29th** day of **March 2023**

....

Registrar of Patents

FORM P2

REPUBLIC OF SOUTH AFRICA
PATENTS ACT, 1978
REGISTER OF PATENTS

Official application No.			Lodging date: Provisional		Acceptance date	
21	01	2022/07007	22		47	17 February 2023
International classification			Lodging date: National phase		Granted date	
51	H03H		23	23 June 2022		29 March 2023
International application no			International filling date		Priority date	
51	PCT/CN2022/082143		23	22 March 2022		10 November 2021

71	Full name(s) of applicant(s)/Patentee(s):
Zhejiang University of Water Resources and Electric Power	

71	Applicant(s) substituted:	Date registrered
71	Assignee(s):	Date registrered

72	Full name(s) of inventor(s):
(1) Wu Xiushan; (2) Xu Lin; (3) Cui Jiamin; (4) Yao Wei; (5) Peng Tao; (6) Yan Shubin; (7) Zhu Zhenyu	

Priority claimed:	Country	Number	Date
	CN	202111324640.4	10 November 2021

54	Title of invention
A method for rapidly forming a cavity structure of film bulk acoustic resonator	

Address of applicant(s)/patentee(s):
No. 508, 2nd Street, Hangzhou Economic and Technological Development Zone, Zhejiang Province, China

74	Address for service
Sibanda and Zantwijk, Oaktree Corner, 9 Kruger Street, Oaklands (PO Box 1615 Houghton 2041), Johannesburg, 2192, SOUTH AFRICA Reference no.: PT_NP_ZA00002732 ([InsID:])	

61	Patent of addition No.	Date of any change
Fresh application based on.		Date of any change

说 明 书 摘 要

本发明公开了一种快速形成微声薄膜谐振器空腔结构的方法，属于薄膜体声波谐振器技术领域。在基体硅上刻蚀出凹槽，在所述凹槽底部中形成第一牺牲层，在所述第一牺牲层上方和所述凹槽内壁形成第二牺牲层，在所述第二牺牲层中心形成第三牺牲层，然后在所述第三牺牲层上形成支撑层；再于所述支撑层上形成底电极，利用湿法腐蚀先去除所述第二牺牲层，再去除所述第一牺牲层和所述第三牺牲层，最后在所述底电极上形成压电层和顶电极，形成微声薄膜谐振器空腔结构；所述支撑层不能完全覆盖所述第二牺牲层。通过设计特定的三层牺牲层结构，然后利用湿法腐蚀先去除中间的牺牲层，增大腐蚀液与上下两层牺牲层的接触面积，达到快速形成空腔结构的目的。

VERIFICATION OF TRANSLATION

I, the undersigned translator, competent in the original language listed below and English, hereby solemnly and sincerely declare that the following is, to the best of my knowledge and belief, a true and correct translation of the document listed below in a form that best reflects the intention and meaning of the original text.

Original document: PCT/CN2022/082143
Original language: Chinese
Name of translator: zheng xiang
Date: 2022.6.23

zheng xiang
Signature of translator

A method for rapidly forming a cavity structure of film bulk acoustic resonator

TECHNICAL FIELD

This invention relates to the field of belonging to the field of film bulk acoustic resonator, particularly relates to a method for rapidly forming a cavity structure of film bulk acoustic resonator.

BACKGROUND

Film Bulk Acoustic Resonator (FBAR) is a new miniaturized RF resonator, which has the advantages of low insertion loss, high quality factor, high effective electromechanical coupling coefficient and high stability. The working frequency of the thin film bulk acoustic resonator can reach 500MHz~10GHz, the quality factor can reach 1000 or above, and it also has a good temperature coefficient. What is important is that it can be integrated with the current RFIC process, making RF device even more miniaturized. Therefore, film bulk acoustic resonator is often used as RF filter and duplexer in the current mobile communication technology industry. FBAR is favored by researchers because of its small size and high quality factor. In recent years, sensors based on FBAR devices are also emerging one after another, which are often used in research fields such as micro-quality detection, biosensing, parameter monitoring of harsh and narrow environment and so on.

FBAR is mainly composed of silicon substrate, lower electrode layer, piezoelectric layer and upper electrode layer. There are three conventional structures, which are back etching type, cavity type and Bragg type, among which cavity type FBAR is the most widely used one with the best device performance and relatively easy processing.

When FBAR works, the piezoelectric film vibrates under the action of the electric signals transmitted by the upper and lower electrodes, which excites the bulk acoustic wave propagating along the longitudinal direction of the film. When the bulk acoustic wave is transmitted to the side where the top electrode is in contact with the outside air and the side where the bottom electrode is in contact with the outside air, the acoustic impedance of the air can be approximately zero under ideal conditions, so that the acoustic wave is reflected up and down in the structure of the upper electrode-piezoelectric layer-lower electrode of FBAR. However, in practical engineering applications, the structure of upper electrode-piezoelectric layer-lower electrode is often fabricated on silicon substrate by magnetron sputtering and chemical vapor deposition in MEMS technology. In order to ensure that the sound wave can be completely confined inside the film, in where the sound wave cannot leak because that the outer side of the upper surface of the device has been in contact with the air, while the lower side is connected with the substrate, it is necessary to take measures to limit the leakage of the sound wave, so it often uses the design of cavity structure at the lower side of the structure to prevent the leakage of the sound wave. As far as the shape of electrode layer and piezoelectric layer is concerned, it is usually considered to design them into irregular polygons, so as to minimize the parasitic resonance of the device during operation and reduce the influence on the performance of bulk acoustic wave devices.

The quality of the cavity structure directly affects the quality factor and electromechanical coupling coefficient of the film bulk acoustic resonator. The excellent cavity structure can vibrate the piezoelectric layer of FBAR under the action of alternating current, and excite the bulk acoustic wave propagating along the longitudinal direction of the thin film that is confined to the upper electrode-piezoelectric layer-lower electrode structure for up and down reflection. If bulk acoustic waves leak into the silicon substrate due to the loose cavity structure, the quality factor and electromechanical coupling coefficient of FBAR will be affected. However, in the actual cavity preparation process, the cavity structure is often formed by etching a concave groove on the substrate, filling a single sacrificial layer material in the groove, and then removing the sacrificial layer material by wet etching or dry etching to form the cavity structure.

However, in the traditional method of etching the sacrificial layer, the contact area between the etching solution and the etching gas and the sacrificial layer material is small, therefore, causing a long release time of the sacrificial layer, which is not conducive to the continuous development of the subsequent film preparation. Moreover, if the device is exposed in corrosive environment for too long, and other film layers would be damaged to varying degrees, and, if the reaction rate is too fast, the substrate and other film layers of the device would be damaged, thus affecting the yield of the device and the film forming speed. The traditional method is not only costly, but also unfavorable for large-scale production. Therefore, it is necessary to find a low-cost method that can form the cavity structure relatively quickly.

SUMMARY

The purpose of this invention is to provide a method for rapidly forming a cavity structure of film bulk acoustic resonator, which designs a specific three-layer sacrificial layer structure, and then remove the middle sacrificial layer by wet etching to increase the contact area between the etching solution and the upper and lower sacrificial layers, so as to quickly form the cavity structure.

In order to achieve the purpose of this invention, this invention provides the technical solutions as followings:

One solution of this invention is to provide a method for rapidly forming a cavity structure of film bulk acoustic resonator that comprises the following steps: etching a groove on the silicon substrate, forming a first sacrificial layer in the bottom of the groove, forming a second sacrificial layer above the first sacrificial layer and on the inner wall of the groove, forming a third sacrificial layer at the center of the second sacrificial layer, and then forming a support layer on the third sacrificial layer; forming a bottom electrode on the support layer, removing the second sacrificial layer by wet etching, then removing the first sacrificial layer and the third sacrificial layer, and finally forming a piezoelectric layer and a top electrode on the bottom electrode to form a cavity structure of the film bulk acoustic resonator; the support layer cannot completely cover the second sacrificial layer.

Preferably, the depth of the groove is 0.8-1.1μm; The thickness of the first sacrificial layer is 300-400μm; The thickness of the second sacrificial layer is 200-300μm; The thickness of the third sacrificial layer is 300-400μm.

Preferably, the second sacrificial layer formed by the inner wall of the groove is flush with the silicon substrate around the groove.

Preferably, the third sacrificial layer is formed, it is ground to be flush with the surroundings.

Preferably, the materials of the first sacrificial layer and the third sacrificial layer include Si_3N_4 or amorphous silicon; The material of the second sacrificial layer includes metal oxide or metal nitride.

Preferably, the metal oxide is ZnO and the metal nitride is AlN.

Preferably, the material of the supporting layer is Si_3N_4, and the thickness of the supporting layer is 300nm.

Preferably, the etching solution selected for wet etching is alkaline solution.

In this invention, the alkaline solution is selected as the etching solution and the first, second and third sacrificial layers of specific materials, so that the second sacrificial layer reacts with the etching solution first and then reaction with the first and third sacrificial layers. The second sacrificial layer in the middle is corroded first, which can further increase the contact area of the reaction and accelerate the corrosion rate of the first and third layers.

Preferably, the method of forming the first sacrificial layer, the second sacrificial layer, the third sacrificial layer, the support layer, the bottom electrode, the piezoelectric layer and the top electrode includes magnetron sputtering or chemical vapor deposition.

The beneficial effects of this invention are described as followings:

According to the invention, a specific three-layer sacrificial layer structure is designed, and then the middle sacrificial layer is first removed by wet etching, in order to increase the contact area between the etching solution and the upper and lower sacrificial layers, thus achieving the purpose of rapidly forming the cavity structure.

According to the preparation method provided by the invention, if the second sacrificial layer is AlN, 1μm AlN in 40% KOH alkaline solution can be completely etched in only 3-4 s at 80℃, and if the first and third sacrificial layers are amorphous silicon, 2μm AlN in 40% KOH alkaline solution can be completely etched in about 15 minutes at 80℃.

The preparation method provided by the invention can not only prevent the substrate of the device and other film layers from being damaged due to fast reaction rate; moreover, it can also solve the defects of small contact area between corrosion solution and sacrificial material, as well as the long release time of sacrificial material.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a top view of the third deposition layer of the present invention;

Fig. 2 is a schematic view of the longitudinal section of each film layer before the release of the sacrificial layer of the present invention;

Fig. 3 is a schematic diagram of the wet etching process of the present invention;

Wherein: 101, silicon substrate; 102, the second sacrificial layer; 103, the third sacrificial layer; 104, the first sacrificial layer; 105, the support layer; 106, the bottom electrode.

DETAILED DESCRIPTION OF THE INVENTION

Now, various exemplary embodiments of the present invention will be described in detail. This detailed description should not be considered as a limitation of the present invention, but should be understood as a more detailed description of some aspects, characteristics and embodiments of the present invention. It should be understood that the terms used in this invention are only for describing specific embodiments, and are not used to limit the invention.

In addition, for the numerical range in the present invention, it should be understood that each intermediate value between the upper limit and the lower limit of the range is also specifically disclosed. Any stated value or intermediate value within the stated range and any other stated value or every smaller range between intermediate values within the stated range are also included in the present invention. The upper and lower limits of these smaller ranges can be independently included or excluded from the range.

Unless otherwise specified, all technical and scientific terms used herein have the same meaning as commonly understood by the ordinary technicians in the field of this invention. Although the present invention only describes the preferred methods and materials, any methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present invention. The words "including", "including", "having" and "containing" used in this paper are all open terms, that is, they mean including but not limited to.

Embodiment 1

Preparation method of rapidly forming a cavity structure of film bulk acoustic resonator is described as followings:

Step 1: Firstly, on the surface of the silicon substrate 101, the groove window of the sacrificial layer is photoetched with reverse glue, and then the groove is etched on the substrate silicon 101 by deep reactive ion etching, and the depth of the groove is 0.8 μm.

Step 2: A first sacrificial layer of amorphous silicon 104 with a thickness of 300nm is formed at the bottom of the groove by vapor deposition.

Step 3, Designing the mask reticle according to the shape of the groove, depositing an AlN layer with a thickness of 200nm on the first sacrificial layer 104 formed in step 2, and depositing an AlN layer with a thickness of 300nm on the inner wall of the groove to form the second sacrificial layer 102.

Step 4, At the center of the second sacrificial layer 102 formed in step 3, a third sacrificial layer 103 of amorphous silicon is formed by vapor deposition with a thickness of 300nm.

Step 5: The second sacrificial layer 102 and the third sacrificial layer 103 in the groove are polished by chemical mechanical polishing until they are flush with the base silicon 101. At this time, the composite sacrificial layer is deposited, and the top view of the device is shown in Figure 1.

Step 6: Form the Si_3N_4 support layer 105 by vapor deposition with a thickness of 300nm. The support layer 105 needs to cover the groove part, but a release channel for releasing the sacrificial layer needs to be reserved.

Step 7: Using positive lithography mask reticle, the bottom electrode 106 of Mo (inert metal, which is not corroded by etching solution) is formed by vapor deposition (pentagonal in this embodiment) with a thickness of 200nm, and the schematic diagram of the longitudinal section of the device is shown in Figure 2.

Step 8, release the sacrificial layer, and place the device after the above steps in the aqueous solution of KOH, during which the stirring is increased to provide the etching rate. The KOH solution and the second sacrificial layers 102(AlN) located at both sides of the groove are in contact and react first. Because the reaction rate between KOH and AlN is faster, the second sacrificial layers 102(AlN) located at both sides of the groove are first etched to form through holes, and then KOH etching solution can enter the composite sacrificial layer and begin to etch the second sacrificial layer 102 located in the middle.

When the middle second sacrificial layer 102 is completely etched, the KOH solution can completely enter the composite sacrificial layer. At this time, the KOH solution can etch the third sacrificial layer 103 (amorphous silicon) and the first sacrificial layer 104 (amorphous silicon) from top to bottom, respectively, thus accelerating the rate of cavity formation. The process of KOH solution entering the composite sacrificial layer by wet etching is shown in Figure 3.

Step 9: After the wet etching, the device is washed and dried. At this time, the sacrificial layer has been released, and the support layer 105 and the bottom electrode 106 have been prepared. Next, a subsequent piezoelectric layer and a top electrode are formed on the upper end of the bottom electrode 106 to form the cavity structure of the film bulk acoustic resonator.

Embodiment 2

Preparation method of rapidly forming a cavity structure of film bulk acoustic resonator is described as followings:

Compared with Embodiment 1, the differences of this embodiment are described as followings: in step 1 the groove depth is 1.1 μm; in step 2, the thickness of the first sacrificial layer 104 is 400nm, in step 3, the thickness of the second sacrificial layer 102 deposited on the first sacrificial layer 104 is 300nm, and the thickness of the deposited part on the inner wall of the groove is 200nm; in step 4, the thickness of the third sacrificial layer 103 is 300nm, Other conditions are the same as in Embodiment 1.

According to the method described in embodimentq 1-2, the inner wall of the finally manufactured cavity structure has no residue of sacrificial layer material, and the bottom is flat, and the lower surface of the support layer has no residue of sacrificial layer and no cracking phenomenon.

Comparative Embodiment 1

Preparation method of rapidly forming a cavity structure of film bulk acoustic resonator is described as followings:

Compared with Embodiment 1, the difference is that the composite sacrificial layer is replaced by a sacrificial layer made of AlN, and other parameters are the same as those of Embodiment 1. According to the method described in Comparative embodiment 1, the inner corrosion of the finally manufactured cavity structure is serious, the inner wall of the cavity is damaged, and the supporting layer is prone to cracking.

Comparative Embodiment 2

Preparation method of rapidly forming a cavity structure of film bulk acoustic resonator is described as followings:

Compared with Embodiment 1, the difference is that the material of the first sacrificial layer is replaced by AlN (the obtained item is a composite sacrificial layer that is composed of two sacrificial layers), and other parameters are the same as those of Embodiment 1. According to the method described in Comparative Embodiment 1, the substrate part of the finally manufactured cavity structure is severely corroded and uneven, and the lower surface of the support layer is easy to leave the sacrificial layer material residue.

The reasons for the above phenomenon are as follows: Due to the rapid reaction between AlN and alkaline KOH solution, if the sacrificial layer is all made of AlN, the 1μm sacrificial layer in a single device will be etched in 2~3s at 80℃ and 40% KOH alkaline environment. Because it is manufactured in batches on the wafer, the sacrificial layer of each group can not be completely released within 2~3s. Then there are some device units in which the sacrificial layer has been completely corroded and released within 2~3s, and then the cavity is filled with KOH solution, which causes the inner wall of the cavity to be corroded, even other film layers to be corroded, and finally the device performance is affected.

If the material of the first sacrificial layer is AlN and the material of the second sacrificial layer is amorphous silicon, because of the fast reaction speed between AlN and KOH solution, the first sacrificial layer is corroded completely, and the alkaline solution enters the sacrificial layer and corrodes the amorphous silicon upwards. At this time, because the reaction rate between amorphous silicon and KOH alkaline solution is slow, the contact time between the alkaline solution and the substrate at the bottom of the cavity is increased, causing corrosion damage inside the cavity, thus affecting the device performance.

The above-mentioned embodiments only describe the preferred mode of the present invention, and do not limit the scope of the present invention. Without departing from the design spirit of the present invention, all kinds of modifications and improvements made by ordinary technicians in the field to the technical scheme of the present invention should fall within the protection scope determined by the claims of the present invention.

CLAIMS

1. A method for rapidly forming a cavity structure of film bulk acoustic resonator is characterized in comprising the following steps: etching a groove

on the silicon substrate (101), forming a first sacrificial layer (104) in the bottom of the groove, forming a second sacrificial layer (102) above the first sacrificial layer (104) and on the inner wall of the groove, forming a third sacrificial layer (103) at the center of the second sacrificial layer (102), and then forming a support layer (105) on the third sacrificial layer (103); forming a bottom electrode (106) on the support layer (105), removing the second sacrificial layer (102) by wet etching, then removing the first sacrificial layer (104) and the third sacrificial layer (103), and finally forming a piezoelectric layer and a top electrode on the bottom electrode (106) to form a cavity structure of the film bulk acoustic resonator; The support layer (105) cannot completely cover the second sacrificial layer (102).

2. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the depth of the groove is 0.8-1.1μm; The thickness of the first sacrificial layer (104) is 300-400μm; The thickness of the second sacrificial layer (102) is 200-300μm; The thickness of the third sacrificial layer (103) is 300-400μm.

3. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the second sacrificial layer (102) formed by the inner wall of the groove is flush with the silicon substrate (101) around the groove.

4. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that after the third sacrificial layer (103) is formed, it is ground to be flush with the surroundings.

5. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the materials of the first sacrificial layer (104) and the third sacrificial layer (103) include Si_3N_4 or amorphous silicon; The material of the second sacrificial layer (102) includes metal oxide or metal nitride.

6. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the etching solution selected for wet etching is alkaline solution.

7. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the material of the support layer (105) is Si_3N_4.

8. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the thickness of the support layer (105) is 200-300 nm.

9. A method for rapidly forming a cavity structure of film bulk acoustic resonator, according to claim 1, is characterized in that the method of forming the first sacrificial layer (104), the second sacrificial layer (102), the third sacrificial layer (103), the support layer (105), the bottom electrode, the piezoelectric layer and the top electrode includes magnetron sputtering or chemical vapor deposition.

FIGURE

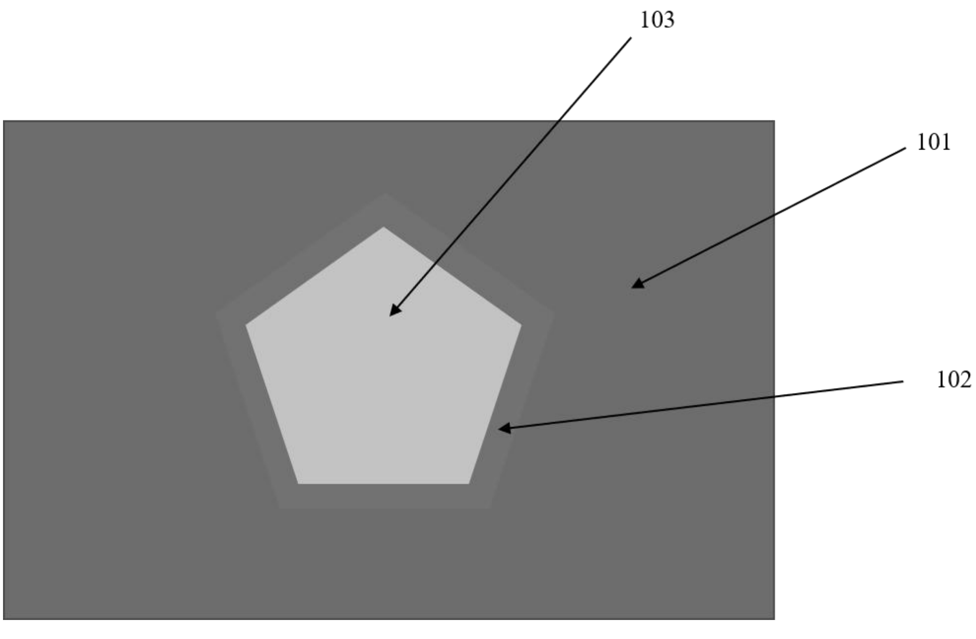


Figure 1

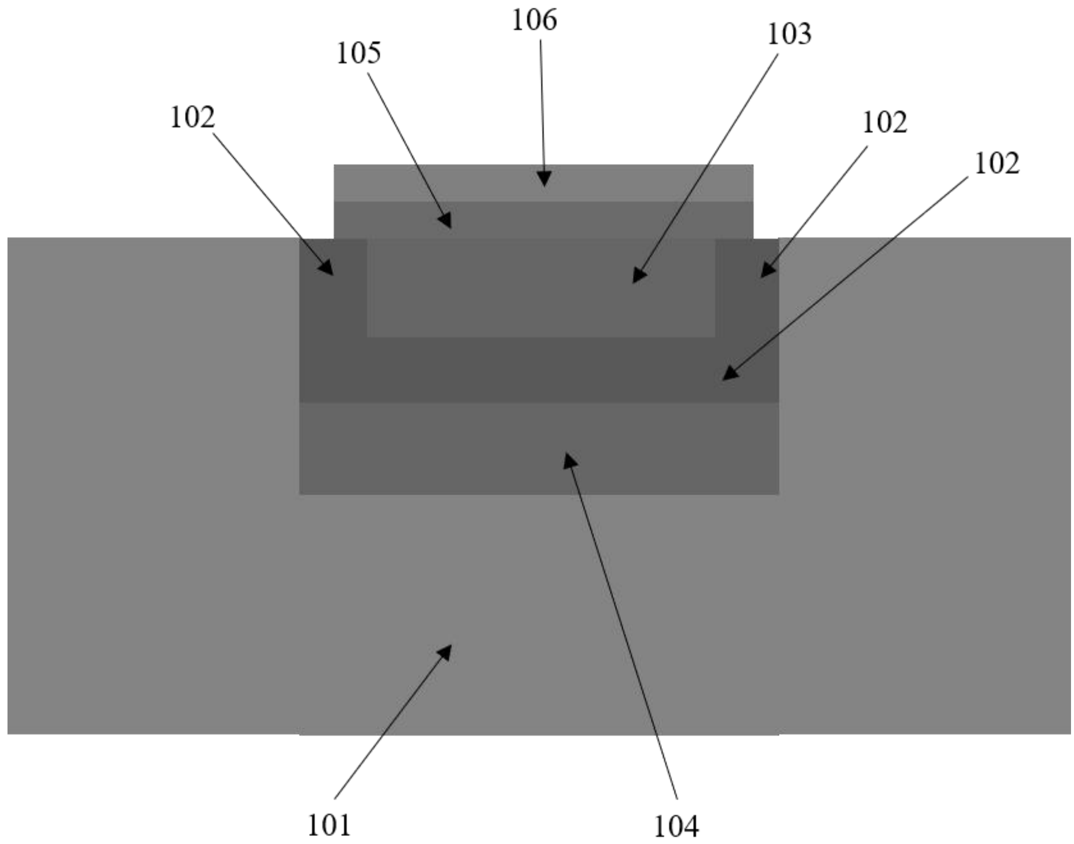


Figure 2

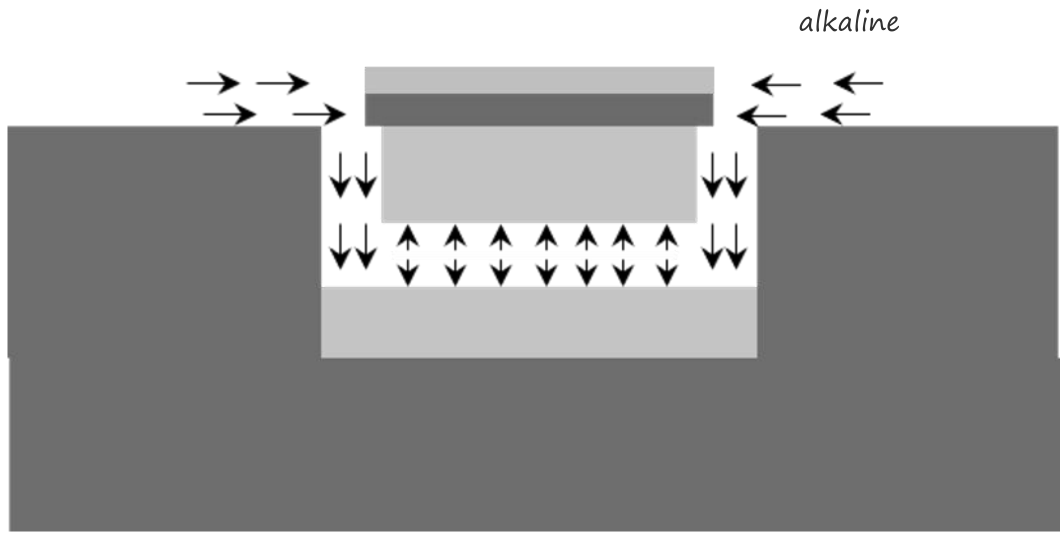
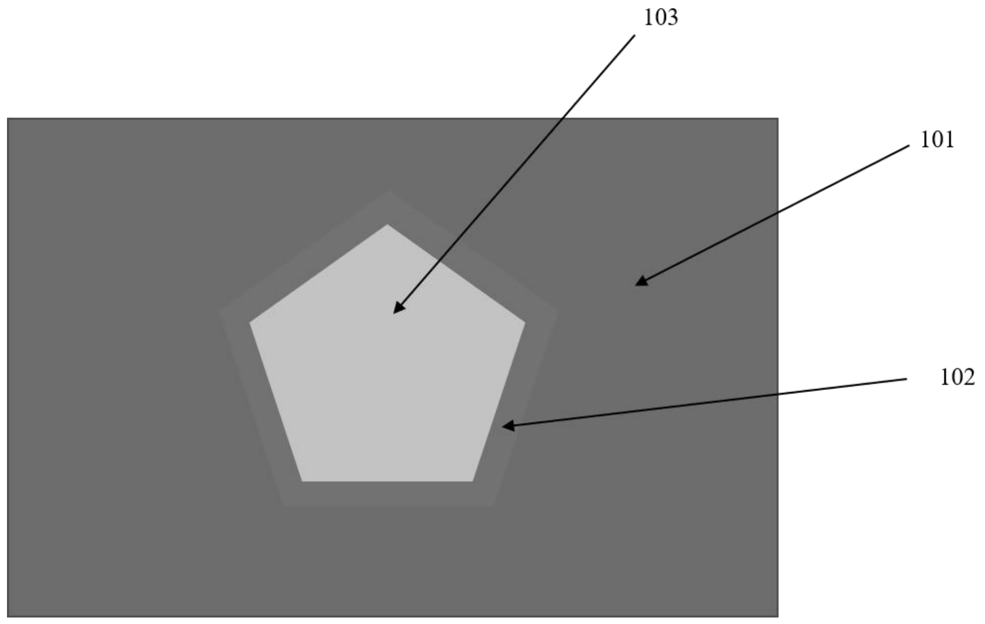


Figure 3

ABSTRACT

This invention provides a method for rapidly forming a cavity structure of film bulk acoustic resonator, belonging to the field of film bulk acoustic resonator. Etching a groove on the silicon substrate, forming a first sacrificial layer in the bottom of the groove, forming a second sacrificial layer above the first sacrificial layer and the inner wall of the groove, forming a third sacrificial layer in the center of the second sacrificial layer, and then forming a support layer on the third sacrificial layer; forming a bottom electrode on the support layer, removing the second sacrificial layer by wet etching, next, removing the first sacrificial layer and the third sacrificial layer, and finally forming piezoelectric layer and top electrode on the bottom electrode to form a cavity structure of the micro-acoustic film resonator; the support layer cannot completely cover the second sacrificial layer. By designing a specific three-layer sacrificial layer structure, and then removing the middle sacrificial layer by wet etching, the contact area between the etching solution and the upper and lower sacrificial layers can be increased, which achieves the purpose of forming the cavity structure.

Abstract Figure


103
101
102