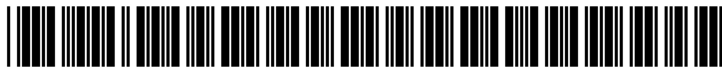

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TAKEZAKI et al.

(54) **CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER AND ULTRASONIC IMAGING APPARATUS USING THE SAME**

(71) Applicant: **HITACHI, LTD.**, Tokyo (JP)

(72) Inventors: **Taiichi TAKEZAKI**, Tokyo (JP); **Shuntaro MACHIDA**, Tokyo (JP); **Daisuke RYUZAKI**, Tokyo (JP); **Yasuhiro YOSHIMURA**, Tokyo (JP); **Tatsuya NAGATA**, Tokyo (JP); **Naoaki YAMASHITA**, Tokyo (JP)

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(57) **ABSTRACT**

A capacitive micromachined ultrasonic transducer **111**A includes: a silicon substrate **101**; an insulating film **102** formed over the silicon substrate **101**; a lower electrode **103**; insulating films **104** and **106**; a cavity **105** constituted by a void formed in a portion of the insulating film **106**; an upper electrode **107**; insulating films **108** and **114**; and a protective film **109**. In addition, the insulating film **106**, upper electrode **107**, insulating film **108** and insulating film **114** above the cavity **105** configure a vibration film **110**, and the protective film **109** above the vibration film **110** is divided into a plurality of isolated patterns regularly arranged with a gap **115** having a constant spacing formed therebetween.

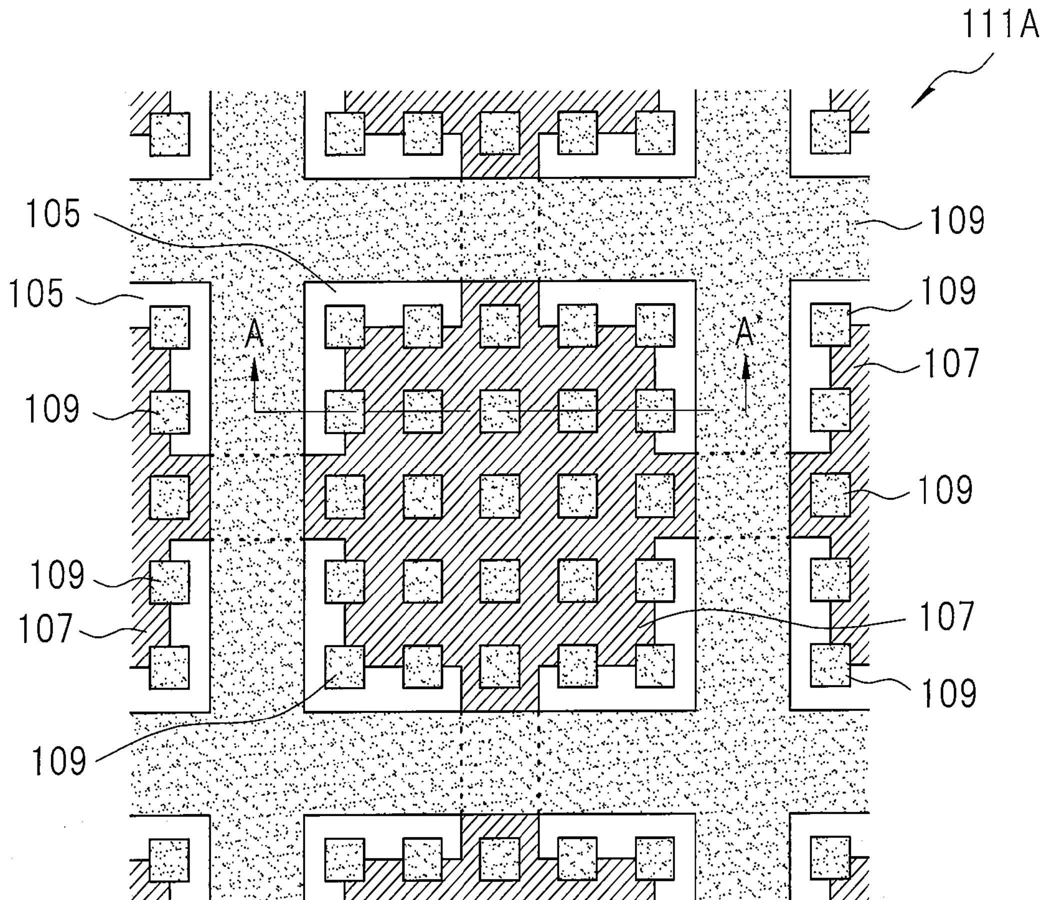


FIG. 1

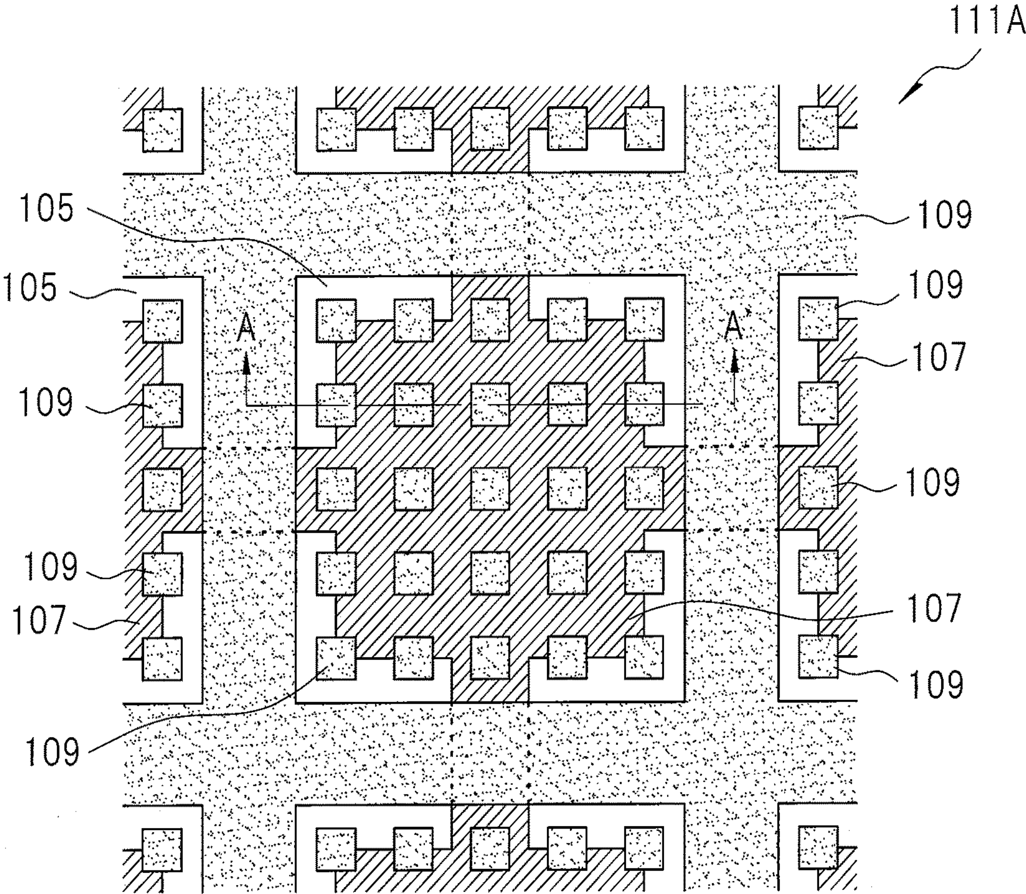


FIG. 2

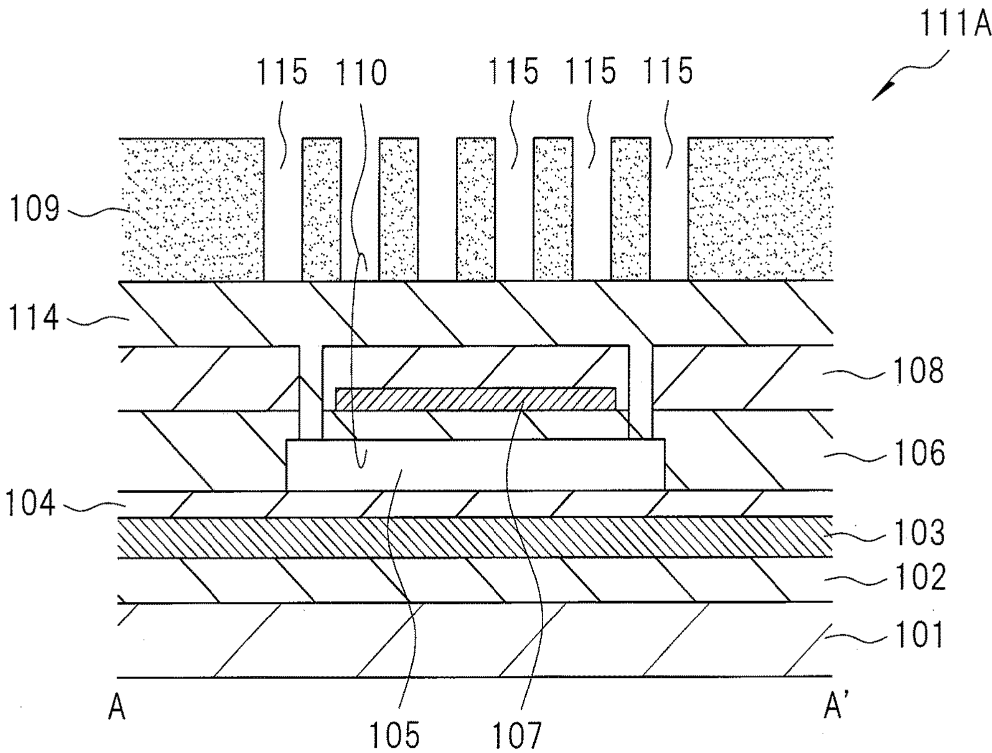


FIG. 3

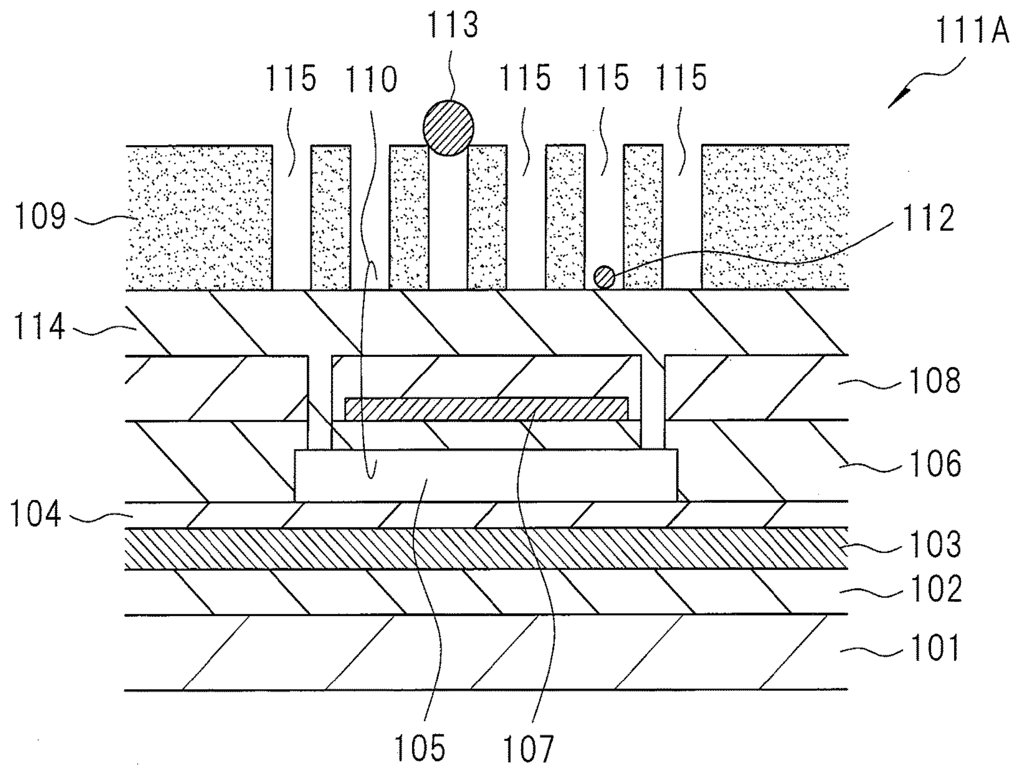


FIG. 4

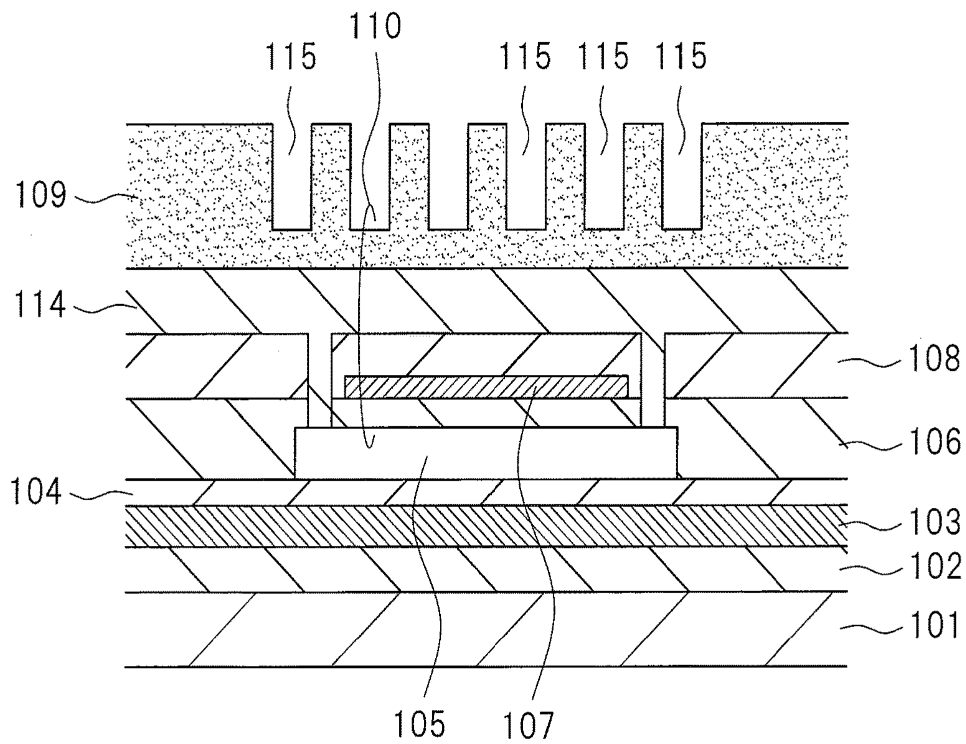


FIG. 5

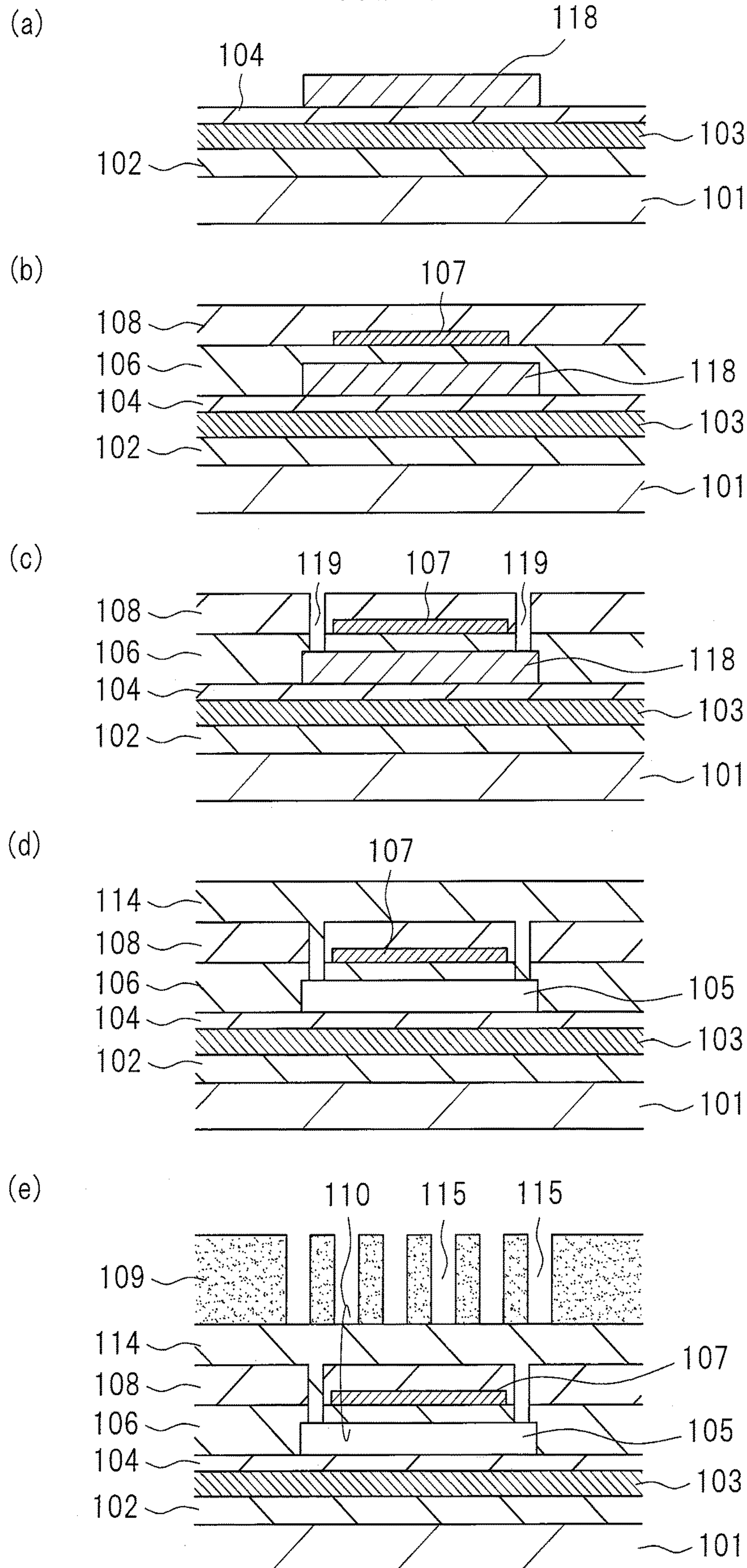


FIG. 6

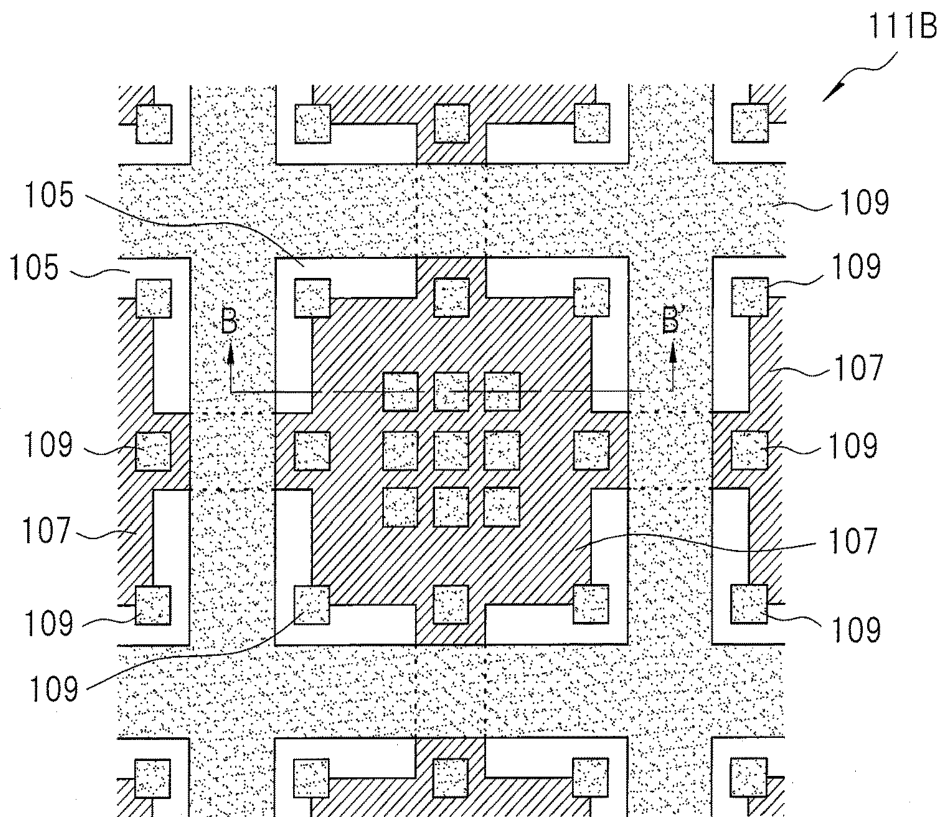


FIG. 7

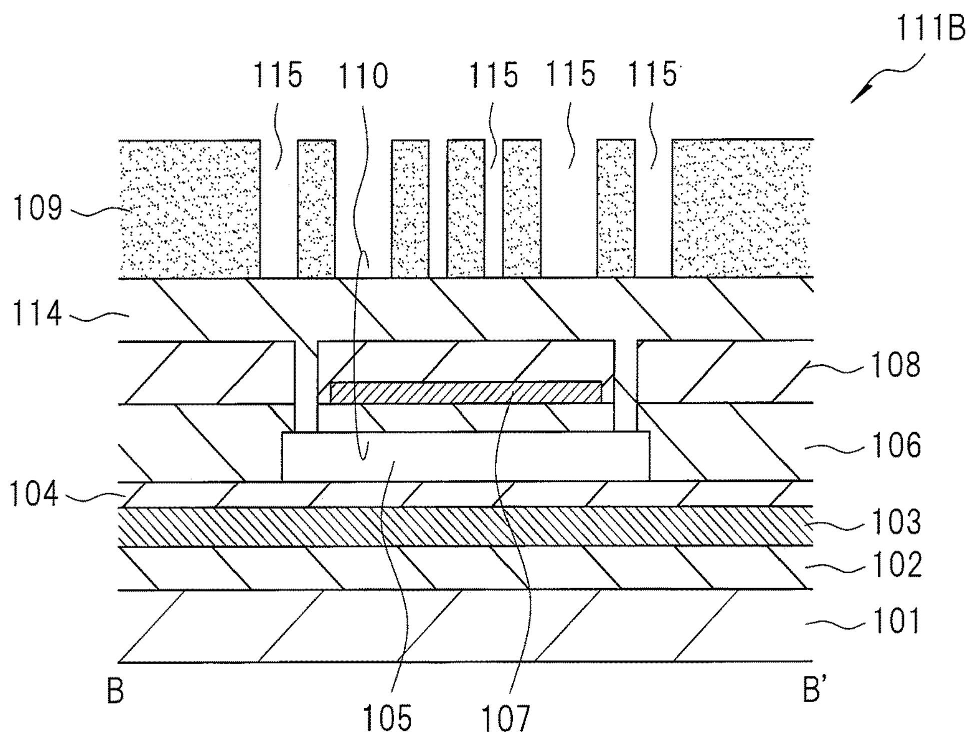


FIG. 8

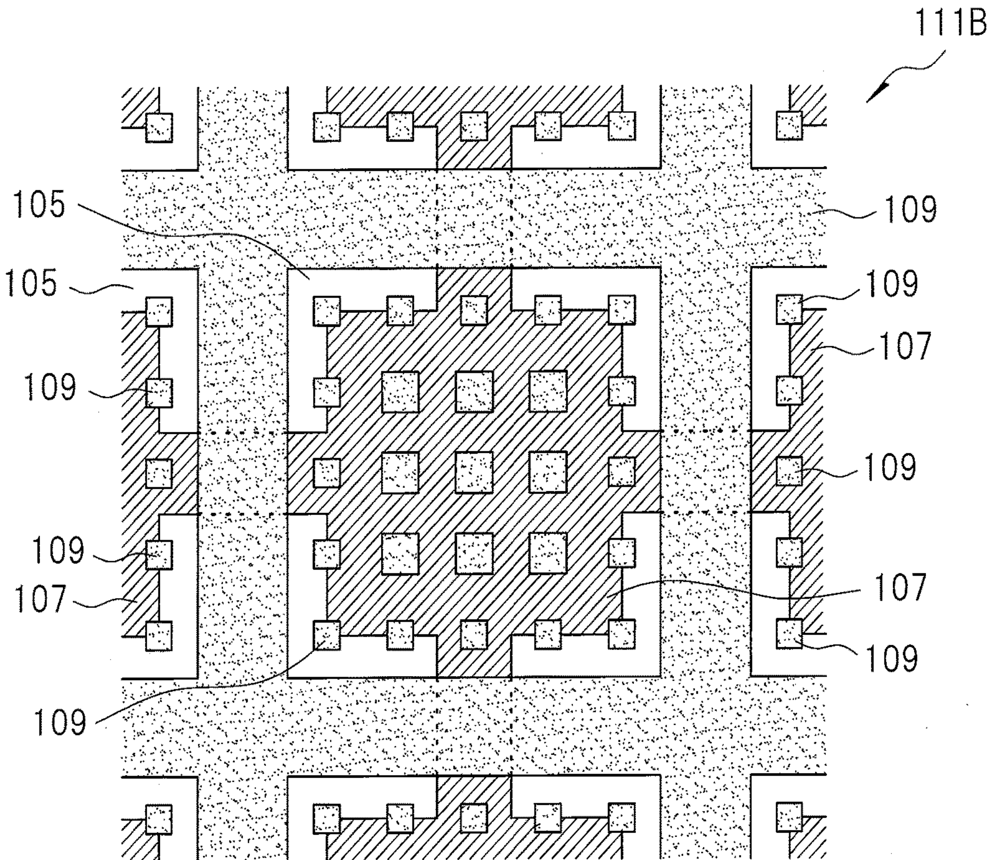


FIG. 9

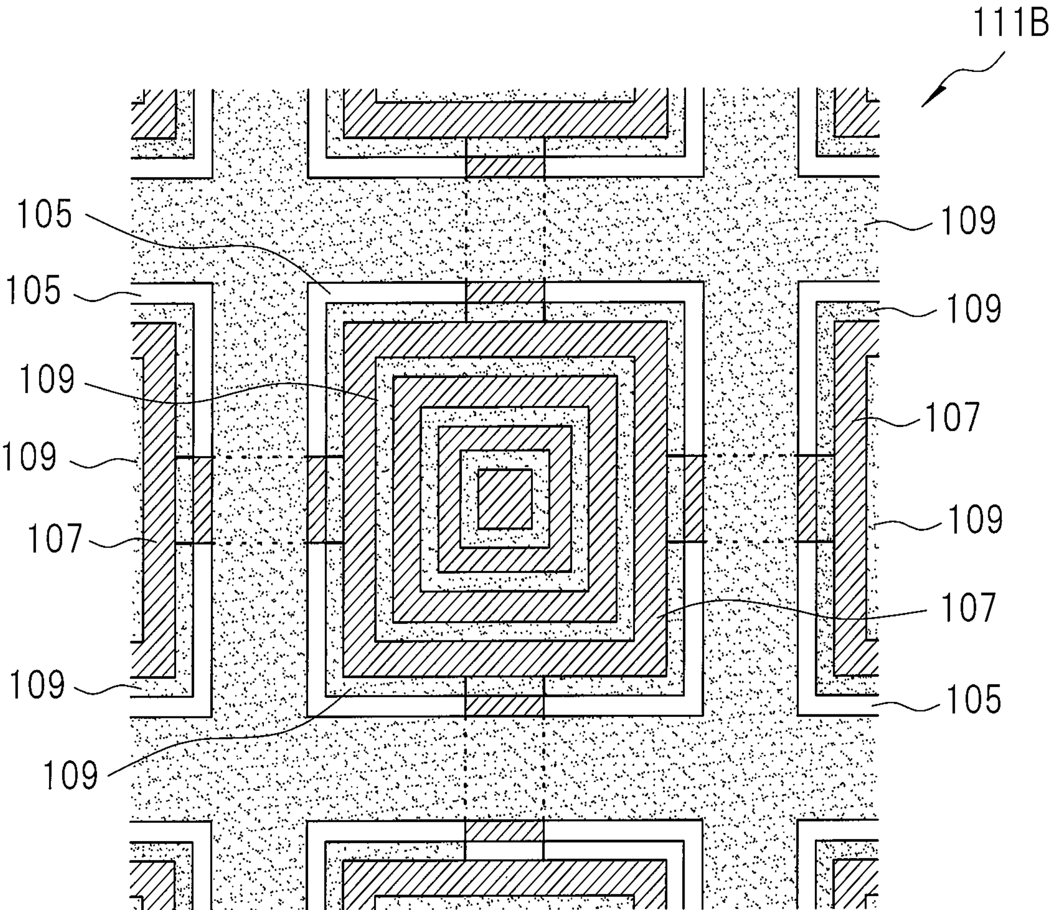


FIG. 10

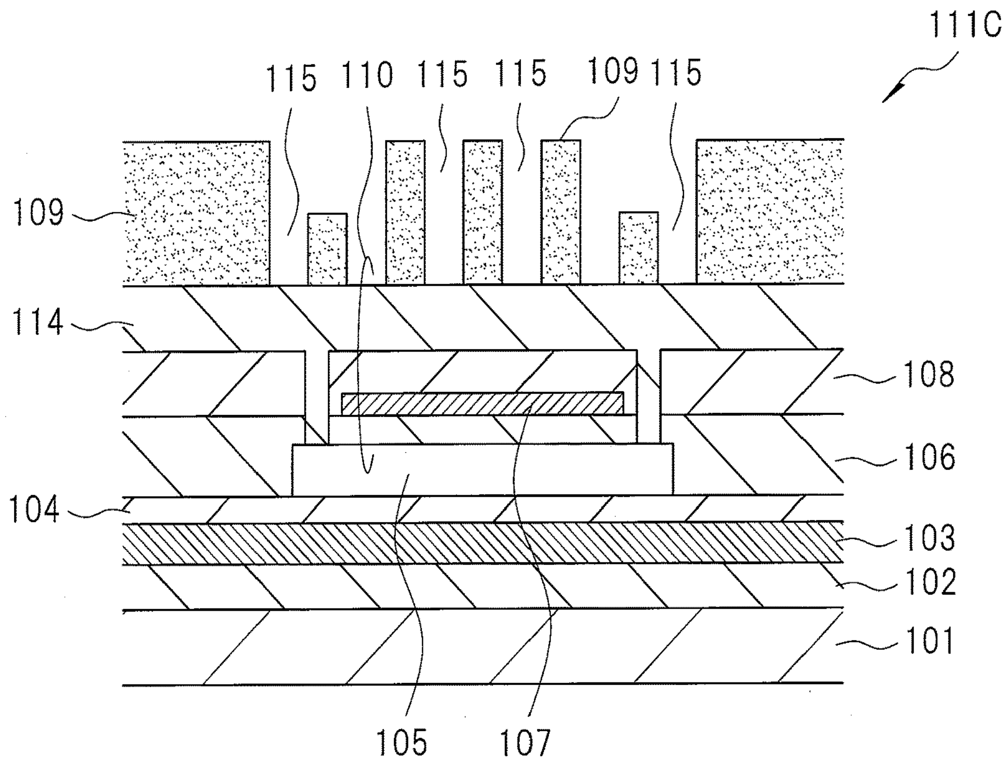


FIG. 11

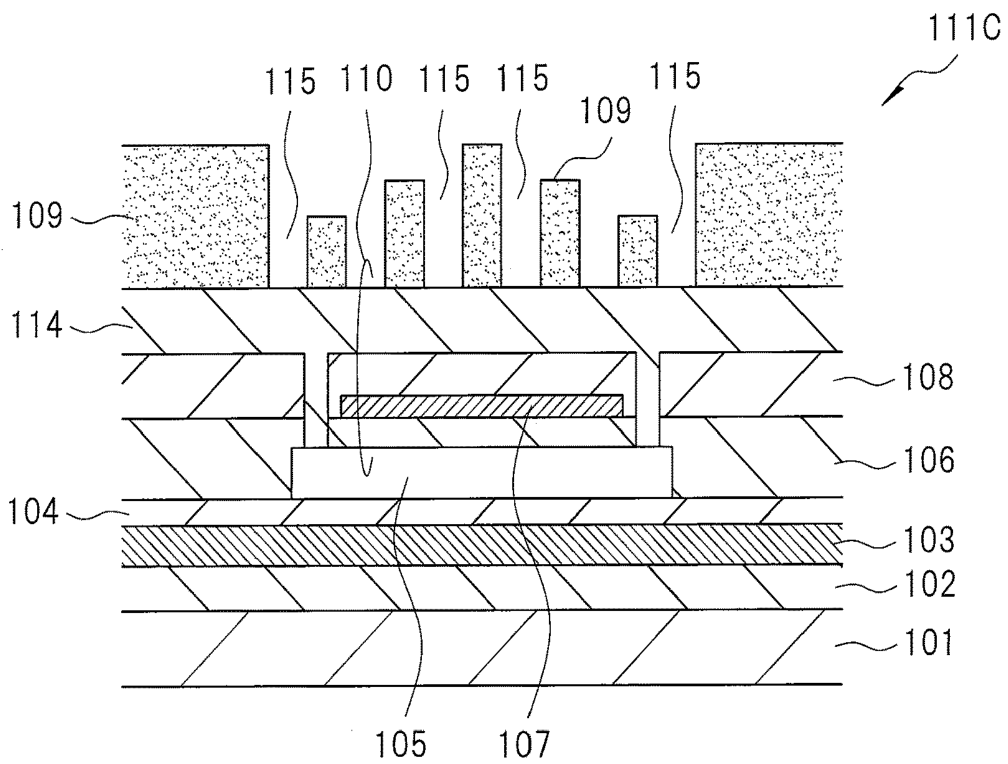


FIG. 12

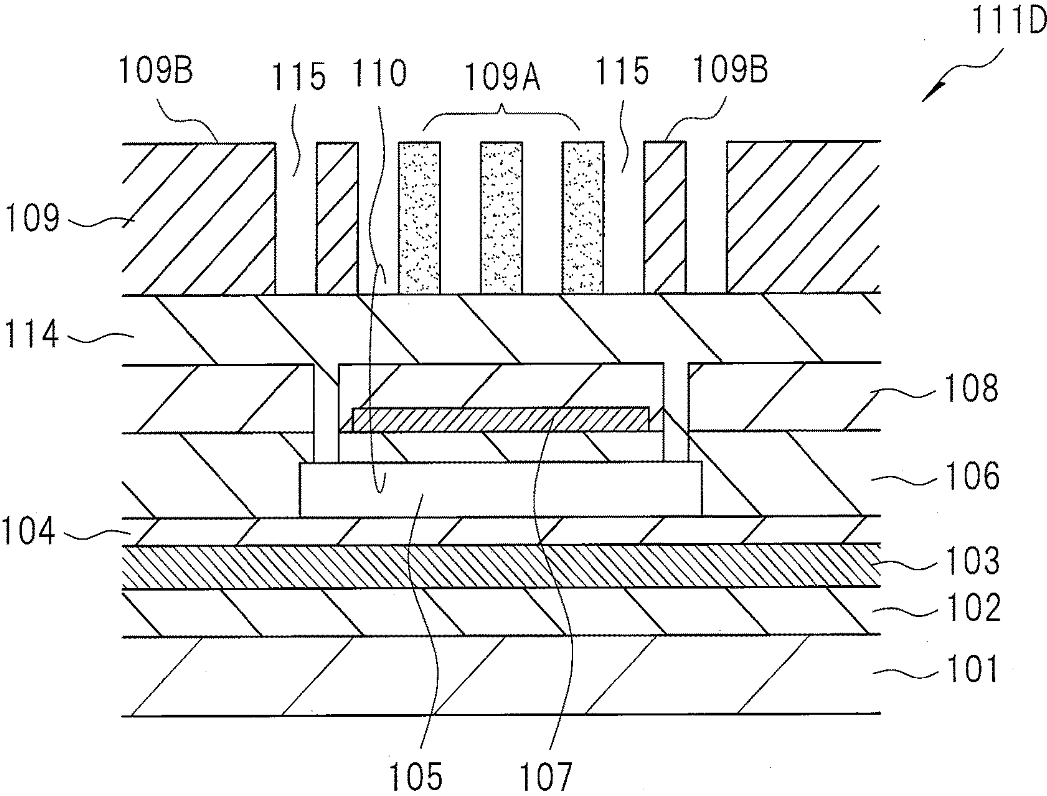
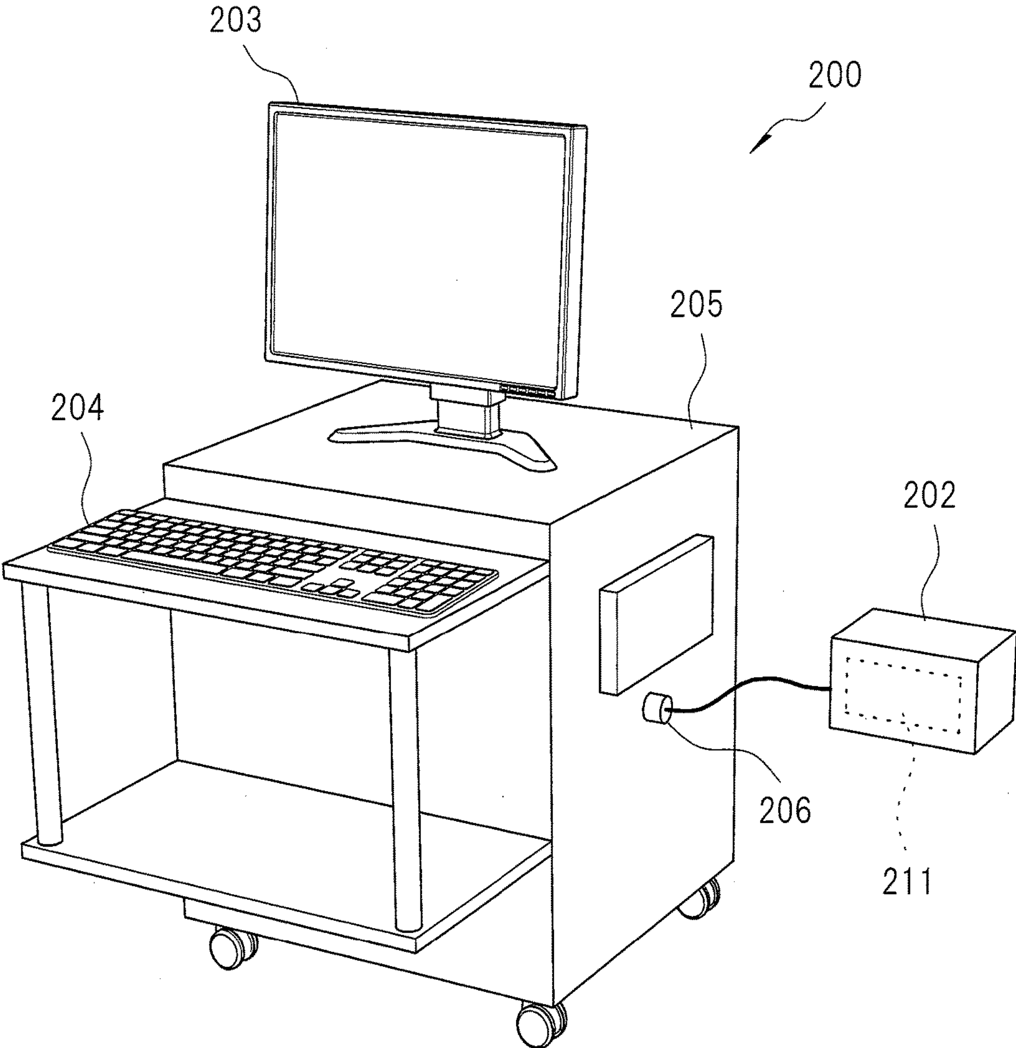


FIG. 13



CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER AND ULTRASONIC IMAGING APPARATUS USING THE SAME

TECHNICAL FIELD

[0001] The present invention relates to a capacitive micromachined ultrasonic transducer and an ultrasonic imaging apparatus using the same.

BACKGROUND ART

[0002] Conventionally, piezoelectric ceramics typified by PZT (lead zirconate titanate) or the like have been utilized as an electroacoustic conversion element in a probe of an ultrasonic imaging apparatus. However, capacitive micromachined ultrasonic transducers (CMUTs) having wider band characteristics than the piezoelectric ceramics have been attracting more attention and have been subject to research and development for the past few years (Patent Document 1).

[0003] The capacitive micromachined ultrasonic transducer has a a cavity formed above a semiconductor substrate and covered by an insulating film, a lower electrode is arranged on a lower side of the cavity, and a vibration film (diaphragm) that includes an upper electrode is arranged on an upper side of the cavity.

[0004] Here, operating principles of the capacitive micromachined ultrasonic transducer will be described. By applying a voltage between the lower electrode and the upper electrode and generating a potential difference, an electrostatic force is generated in the vibration film above the cavity. When transmitting an ultrasonic wave, the electrostatic force applied to the vibration film is temporally varied by applying an AC voltage superimposed on a DC bias voltage, thereby vibrating the vibration film. On the other hand, when receiving an ultrasonic wave, displacement of the vibration film is detected as a capacitance change between the upper and lower electrodes in a state where a constant DC bias voltage is being applied.

[0005] The capacitive micromachined ultrasonic transducer utilizes a silicon wafer or the like as the substrate and is manufactured by a semiconductor fabricating process. In the final step of the manufacturing process, a protective film made of an organic film or the like is formed over an outermost surface of the capacitive micromachined ultrasonic transducer, and thereafter, thinning of the substrate by backgrinding and singulation by dicing are performed.

[0006] In addition, the singulated capacitive micromachined ultrasonic transducer is bonded to a backing material in order to absorb unnecessary ultrasonic waves radiated on a back side of the substrate. When the transducer is bonded to the backing material, a surface of the capacitive micromachined ultrasonic transducer is pressed into contact. After an electrical connection terminal is attached, an acoustic lens that converges the ultrasonic waves is then attached to a front side of the capacitive micromachined ultrasonic transducer. Then, after electric components are attached as necessary, a probe cable and a case are attached to complete the ultrasonic probe.

RELATED ART DOCUMENTS

Patent Documents

[0007] Patent Document 1: Japanese Unexamined Patent Application

[0008] Publication No. 2010-154734

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

[0009] The protective film formed over the surface of the capacitive micromachined ultrasonic transducer adds excessive mass to the vibration film and occasionally causes a decrease in sensitivity of the vibration film.

[0010] As a countermeasure, it is considered that limiting the formation of the protective film to only the vicinity of the electrodes and wirings of the capacitive micromachined ultrasonic transducer as in Patent Document 1 can suppress a decrease in sensitivity while ensuring insulation properties.

[0011] However, if foreign matter adheres to a region where the protective film is not formed and the surface of the singulated capacitive micromachined ultrasonic transducer is being pressed into contact to be mounted on the backing material, the vibration film is directly pressed by the foreign matter since a cushioning effect by the protective film cannot be obtained. This may lead to destruction of the protective film and cause a decrease in manufacturing yield of the ultrasonic probe. In particular, the ultrasonic transducer operating in a low frequency band has a vibration film that is thin, raising concerns regarding an increase in the probability of destruction.

[0012] Therefore, there is a growing demand to devise the capacitive micromachined ultrasonic transducer such that a decrease in the manufacturing yield can be suppressed without causing a decrease in sensitivity of the vibration film.

[0013] The above-described objects, other objects and novel features of the present invention will be apparent from the description in the present specification and the attached drawings.

Means for Solving the Problems

[0014] The following briefly describes an overview of a representative embodiment disclosed in the present application.

[0015] In the capacitive micromachined ultrasonic transducer according to the representative embodiment, a protective film above a vibration film is divided into a plurality of patterns arranged with a gap having a predetermined spacing formed therebetween.

Effects of the Invention

[0016] According to the representative embodiment of the capacitive micromachined ultrasonic transducer, a decrease in the manufacturing yield can be suppressed without causing a decrease in sensitivity of the vibration film.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a plan view showing a main part of a capacitive micromachined ultrasonic transducer according to a first embodiment;

[0018] FIG. **2** is a cross-sectional view taken along a line A-A' of FIG. **1**;

[0019] FIG. **3** is a cross-sectional view describing an effect of the capacitive micromachined ultrasonic transducer according to the first embodiment;

[0020] FIG. **4** is a cross-sectional view showing a modification of the capacitive micromachined ultrasonic transducer according to the first embodiment;

[0021] FIGS. **5**(*a*) to **5**(*e*) are cross-sectional views each showing a manufacturing method of the capacitive micromachined ultrasonic transducer according to the first embodiment;

[0022] FIG. **6** is a plan view showing a main part of the capacitive micromachined ultrasonic transducer according to a second embodiment;

[0023] FIG. **7** is a cross-sectional view taken along a line B-B' of FIG. **6**;

[0024] FIG. **8** is a plan view showing a modification of the capacitive micromachined ultrasonic transducer according to the second embodiment;

[0025] FIG. **9** is a plan view showing a modification of the capacitive micromachined ultrasonic transducer according to the second embodiment;

[0026] FIG. **10** is a cross-sectional view showing a main part of a capacitive micromachined ultrasonic transducer according to a third embodiment;

[0027] FIG. **11** is a cross-sectional view showing a main part of a modification of the capacitive micromachined ultrasonic transducer according to the third embodiment;

[0028] FIG. **12** is a cross-sectional view showing a main part of a capacitive micromachined ultrasonic transducer according to a fourth embodiment; and

[0029] FIG. **13** is a perspective view showing an ultrasonic imaging apparatus according to a fifth embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0030] Hereinafter, embodiments according to the present invention will be described in detail with reference to the drawings. Note that, in all of the drawings used to describe the embodiments, members having the same functions are denoted by the same reference signs, and redundant descriptions thereof are omitted as appropriate. In addition, in the embodiments, descriptions of the same or similar components will not be repeated in principle unless otherwise particularly necessary. Further, in the drawings used to describe the embodiments, hatched lines may occasionally be added even in a plan view or may occasionally be omitted even in a cross-sectional view in order to make the configuration easier to understand.

First Embodiment

[0031] FIG. **1** is a plan view showing a main part of a capacitive micromachined ultrasonic transducer according to a first embodiment, and FIG. **2** is a cross-sectional view taken along a line A-A' of FIG. **1**.

[0032] The capacitive micromachined ultrasonic transducer **111**A of the first embodiment comprises: a silicon substrate **101**; an insulating film **102** formed over the silicon substrate **101**; a lower electrode **103**; insulating films **104** and **106**; a cavity **105** constituted by a void formed in a portion of the insulating film **106**; an upper electrode **107**; insulating films **108** and **114**; and a protective film **109**. In addition, the insulating film **106**, upper electrode **107**, insulating film **108** and insulating film **114** above the cavity **105** configure a vibration film **110**.

[0033] Examples of materials of the insulating films **102**, **104**, **106**, **108** and **114** include Si_xO_y (silicon oxide), Si_xN_y (silicon nitride), $Si_xO_yN_z$ (silicon oxynitride), Hf_xO_y (hafnium oxide), Y-doped Hf_xO_y (yttrium-doped hafnium oxide), Si-doped Hf_xO_y (silicon-doped hafnium oxide), $La_xTa_yO_z$ (lanthanum oxide+tantalum oxide) and the like. In addition, it is preferable that the film thickness of each of the films is within a range of 10 nm to 5000 nm.

[0034] It is preferable that a height of the cavity **105** is within a range of 10 nm to 5000 nm. FIG. **1** shows an example in which a planar shape of the cavity **105** is a quadrangle. However, the planar shape of the cavity **105** is not limited to be a quadrangle, and may be any shape such as a circle, a polygon or the like. In addition, in a case where the planar shape of the cavity **105** is a quadrangle, it is preferable that a planar size of the cavity **105** is set such that each side has a length within a range of approximately 100 nm to 1000000 nm, depending on a frequency band of the vibration film **110**.

[0035] The electromechanical coupling coefficient which is one of the factors used for determining sensitivity of the capacitive micromachined ultrasonic transducer **111**A increases as a distance between the upper and lower electrodes decreases. However, if this distance is too short, the insulating films interposed between the upper and lower electrodes may come into contact and cause dielectric breakdown, or alternatively, a moving range of the vibration film **110** may become narrowed and prevent a sufficient transmitted acoustic pressure from being obtained. Therefore, it is more preferable that the film thickness of each of the insulating films (insulating film **104** and insulating film **106**) interposed between the upper and lower electrodes is within a range of 10 nm to 1000 nm, and it is more preferable that the height of the cavity **105** is within a range of 10 nm to 1000 nm.

[0036] Examples of materials of the lower electrode **103** and the upper electrode **107** can be selected from metals, highly-concentrated impurity-doped semiconductors and the like, including W, Ti, TiN, Al, Cr, Pt, Au, Si, poly-Si, amorphous-Si and the like. In addition, it is preferable that the film thickness of each of the films is within a range of 10 nm to 1000 nm.

[0037] When a surface of the capacitive micromachined ultrasonic transducer **111**A is being pressed into contact to bond the capacitive micromachined ultrasonic transducer **111**A to a backing material, the protective film **109** provides a cushioning effect against the foreign matter adhered to the surface of the capacitive micromachined ultrasonic transducer **111**A and prevents the vibration film **110** from being directly pressed by the foreign matter which leads to destruction of the vibration film **110**.

[0038] In the capacitive micromachined ultrasonic transducer **111**A of the first embodiment, the protective film **109** above the vibration film **110** is divided into a plurality of isolated patterns regularly arranged with a gap **115** having a constant spacing formed therebetween.

[0039] Examples of the material of the protective film **109** include polyimide resin, polybenzoxazole resin, polydimethylsiloxane resin, parylene resin, polymethyl methacrylate resin and the like. In addition, it is preferable that a film thickness of the protective film **109** is within a range of 100 nm to 10000 nm, depending on the size of the foreign matter adhered to the surface of the capacitive micromachined ultrasonic transducer **111**A. It is preferable that a planar size of each of the isolated patterns in the protective film **109** is within a range of 10 nm to 1000000 nm, depending on the size of the cavity **105**.

[0040] In the first embodiment, the upper electrode **107** is covered by the insulating film **108** and insulating film **114**,

and in a case where the capacitive micromachined ultrasonic transducer **111**A is applied to an ultrasonic imaging apparatus, these become an element that ensures insulation properties between the apparatus and a subject. Further, using a material having insulation properties for the protective film **109** allows the protective film **109** to become another element that ensures insulation properties between the apparatus and the subject.

[0041] In the example shown in FIGS. **1** and **2**, a single lower electrode **103** and a single upper electrode **107** is formed per cavity **105**. However, the lower electrode **103** and the upper electrode **107** may each be divided into a plurality of sections. In this case, a shape of the vibration film **110** can be controlled by transmitting different electric signals to each of the divided electrodes. Alternatively, the divided electrodes may be connected in parallel, so that the same electric signals are transmitted to each of the electrodes.

[0042] Next, effects of the first embodiment will be described. FIG. **3** is a cross-sectional view showing a state where two types of foreign matter having different sizes have adhered to a portion (portion corresponding to the line A-A' of FIG. **1**) of the surface of the capacitive micromachined ultrasonic transducer **111**A.

[0043] The first foreign matter **112** has a size that is smaller than the spacing of the gap **115** in the protective film **109** and is present on a surface of the vibration film **110**. Here, the foreign matter **112** is considered to be the only foreign matter on the surface of the capacitive micromachined ultrasonic transducer **111**A. When the capacitive micromachined ultrasonic transducer **111**A is pressed into contact in this state with using a pressing piece and the capacitive micromachined ultrasonic transducer **111**A is bonded to the backing material, the surface of the protective film **109** becomes the surface in contact with the pressing piece, whereby a cushioning effect is provided by the protective film **109**. In this case, possibility of destruction of the vibration film **110** is low since the vibration film **110** is not directly pressed by the foreign matter **112**.

[0044] On the other hand, the second foreign matter **113** has a size that is larger than the spacing of the gap **115** in the protective film **109** and is present on the surface of the protective film **109**. Here, the foreign matter **113** is considered to be the only foreign matter on the surface of the capacitive micromachined ultrasonic transducer **111**A. When the capacitive micromachined ultrasonic transducer **111**A is pressed into contact in this state with using the pressing piece and the capacitive micromachined ultrasonic transducer **111**A is bonded to the backing material, the foreign matter **113** becomes the surface in contact with the pressing piece, whereby a cushioning effect is provided by the protective film **109**. In this case also, possibility of destruction of the vibration film **110** is low since the vibration film **110** is not directly pressed by the foreign matter **113**.

[0045] In order to obtain a sufficient cushioning effect by the protective film **109**, it is necessary to optimize the thickness of the protective film **109** and the spacing of the gap **115** with respect to the size of the foreign matter. Namely, it is preferable that the thickness of the protective film **109** is greater than the size of the foreign matter such that the foreign matter in contact with the vibration film **110** is not directly pressed. In addition, it is preferable that the spacing of the gap **115** in the protective film **109** is smaller than the size of the foreign matter such that the foreign matter does not directly come in contact with the vibration film **110**. By statistically analyzing the size of the foreign matter that adheres to the capacitive micromachined ultrasonic transducer **111**A during a step of mounting the capacitive micromachined ultrasonic transducer **111**A on the backing material and determining the thickness of the protective film **109** and the spacing of the gap **115** based on the above-described relation, probability of destruction of the vibration film **110** during the mounting step can be reduced.

[0046] In addition, when bonding an acoustic lens to the capacitive micromachined ultrasonic transducer **111**A bonded to the backing material, either the surface of the protective film **109** or the foreign matter becomes the surface in contact with the acoustic lens depending on the size of the foreign matter, whereby a cushioning effect is provided by the protective film **109**. In this case also, possibility of destruction of the vibration film **110** is low since the vibration film **110** is not directly pressed by the foreign matter.

[0047] The first embodiment has described a case where the thickness and planar size of each of the isolated patterns in the protective film **109** are constant across the entire surface of the vibration film **110** and where the spacing of each of the gaps **115** in the protective film **109** is also constant. In this case, a uniform cushioning effect by the protective film can be obtained across the entire surface of the vibration film **110**, whereby probability of destruction of the vibration film **110** caused by the foreign matter adhered during the mounting step is reduced. In addition, it is obvious that the same effects as describe above can be obtained even if the thickness and planar size of the protective film **109** are not constant across the entire surface of the vibration film **110** unlike the case described above.

[0048] FIG. **4** shows an example in which a bottom portion of the gap **115** in the protective film **109** does not reach the surface of the vibration film **110**.

[0049] In this case also, the same effects as those described above in the first embodiment can be obtained. In addition, a cushioning effect that acts against the foreign matter having entered the gap **115** in the protective film **109** is provided by the protective film **109** present at the bottom portion of the gap **115**.

[0050] However, since the protective film **109** is not completely divided into a plurality of isolated patterns in this case, influence of viscoelasticity of the protective film becomes large when a voltage is applied between the upper and lower electrodes and the vibration film **110** is deformed, whereby an amount of deformation becomes unstable and creep deformation in which the amount of deformation varies over a period of time occurs. As a result, a distance between the upper and lower electrodes becomes short during operation and may cause dielectric breakdown to occur. Therefore, from the viewpoint of preventing dielectric breakdown, it is preferable that the protective film **109** is constituted by a plurality of isolated patterns completely separated from each other as in the example shown in FIGS. **1** and **2**.

[0051] As described above, by providing the gap **115** in the protective film **109** above the vibration film **110**, possibility of the foreign matter directly pressing the vibration film **110** is reduced, and thus, probability of destruction of the vibration film **110** during the mounting step is reduced while suppressing a decrease in a mounting yield of the

capacitive micromachined ultrasonic transducer **111**A. In particular, the thin vibration film **110** of the capacitive micromachined ultrasonic transducer **111**A operating in a low frequency band is expected to provide an effect in which the mounting yield is significantly improved.

[0052] Next, a manufacturing method of the capacitive micromachined ultrasonic transducer **111**A of the first embodiment will be described with reference to FIG. **5**. FIG. **5** includes cross-sectional views corresponding to a cross section taken along the line A-A' of FIG. **1**.

[0053] First, as shown in FIG. **5**(*a*), the insulating film **102**, lower electrode **103** and insulating film **104** are sequentially deposited over the silicon substrate **101**, a metal film **118** is then deposited over the insulating film **104**, and thereafter, the metal film **118** is patterned by a lithography method so as to form a shape of the cavity **105**. Note that a semiconductor film, an insulating film or the like may be patterned instead of the metal film **118** so as to form the shape of the cavity **105**.

[0054] Next, as shown in FIG. **5**(*b*), the insulating film **106** is deposited so as to cover the insulating film **104** and the metal film **118**, a metal film (or a highly-concentrated impurity-doped semiconductor film or the like) is then deposited over the insulating film **106** and is patterned by the lithography method to form the upper electrode **107**, and thereafter, the insulating film **108** is deposited so as to cover the insulating film **106** and the upper electrode **107**.

[0055] Next, as shown in FIG. **5**(*c*), the insulating films **108** and **106** above the metal film **118** are etched to form a cavity-forming hole **119** that reaches a surface of the metal film **118**.

[0056] Next, as shown in FIG. **5**(*d*), an etching solution is injected into the cavity-forming hole **119**, the metal film **118** is then melted to form the cavity **105**, and thereafter, the insulating film **114** is deposited over the insulating film **108** to seal the cavity-forming hole **119**.

[0057] Next, as shown in FIG. **5**(*e*), the protective film **109** is formed over the insulating film **114**. The protective film **109** is formed by depositing a protective film material over the insulating film **114** by, for example, a spin-coating method or a vapor-phase growth method such as sputtering, vapor deposition, CVD and the like, and then, if the protective film material is photosensitive, the protective film material is patterned by the lithography method to form the protective film **109** having the gaps **115**. In addition, if the protective film material is non-photosensitive, the insulating film, the metal film, the organic film and the like deposited over the protective film material are patterned by the lithography method, and then, the protective film material is etched with using the pattern as a mask to form the protective film **109** having the gaps **115**.

Second Embodiment

[0058] FIG. **6** is a plan view showing a main part of the capacitive micromachined ultrasonic transducer according to a second embodiment, and FIG. **7** is a cross-sectional view taken along a line B-B' of FIG. **6**.

[0059] The capacitive micromachined ultrasonic transducer **111**B of the second embodiment differs from the capacitive micromachined ultrasonic transducer **111**A of the first embodiment in methods of arranging the isolated patterns in the protective film **109**.

[0060] Namely, in the first embodiment, the thickness and planar size of each of the isolated patterns in the protective film **109** are constant across the entire upper surface of the vibration film **110**, and the spacing of each of the gaps **115** in the protective film **109** is also constant. However, in the example shown in FIGS. **6** and **7**, although the thickness and planar size of each of the isolated patterns are constant across the entire upper surface of the vibration film **110**, the spacing of each of the gaps **115** is not constant. In particular, the number of protective films **109** above a peripheral portion of the vibration film **110** is relatively small, whereas the number of protective films **109** above a center portion of the vibration film **110** is relatively large. In other words, density of the isolated patterns above the peripheral portion of the vibration film **110** is low, whereas density of the isolated patterns above a center portion of the cavity **105** is high.

[0061] Next, effects of the second embodiment shown in FIGS. **6** and **7** will be described. In the capacitive micromachined ultrasonic transducer **111**B of the second embodiment, stiffness of the vibration film **110** is relatively high at its peripheral portion and is relatively low at its center portion. For this reason, when the foreign matter in contact with the vibration film **110** is pressed into contact, destruction is unlikely to occur at the peripheral portion of the vibration film **110** since the amount of deformation is small, whereas destruction is more likely to occur at the center portion of the vibration film **110** since the amount of deformation is large.

[0062] Thus, even if a pattern density of the protective film **109** above the peripheral portion of the vibration film **110** is relatively low, it is considered that there is little influence on destruction of the vibration film **110**.

[0063] On the other hand, from the viewpoint of suppressing a decrease in sensitivity of the vibration film **110**, it is preferable that a mass of the protective film **109** is reduced. Namely, the pattern density of the protective film **109** above the peripheral portion of the vibration film **110** is configured to be relatively low, so that a decrease in both yield and sensitivity can be suppressed.

[0064] In addition, from the viewpoint of creep deformation, it is preferable that the pattern density of the protective film **109** above the peripheral portion of the vibration film **110** is relatively low, and this will be described below.

[0065] When a voltage is applied between the upper and lower electrodes and the vibration film **110** is deformed so as to be recessed, a greater stress is applied to the protective film **109** above the peripheral portion of the vibration film **110** than to the protective film **109** above the center portion of the vibration film **110**. For this reason, the protective film **109** above the peripheral portion of the vibration film **110** has a greater influence on creep deformation than the protective film **109** above the center portion of the vibration film **110**.

[0066] Therefore, the pattern density of the protective film **109** above the peripheral portion of the vibration film **110** is configured to be relatively low as in the second embodiment, so that influence on creep deformation can be reduced. In this manner, from the viewpoint of creep deformation, it is preferable that the pattern density of the protective film **109** above the peripheral portion of the vibration film **110** is relatively low.

[0067] The method of providing the protective film **109** such that the pattern densities differ between the portion above the peripheral portion of the vibration film **110** and the portion above the center portion of the vibration film **110** is

not limited to the example shown in FIGS. **6** and **7**, and the planar size of each of the isolated patterns in the protective film **109** may differ between the portion above the peripheral portion of the vibration film **110** and the portion above the center portion of the vibration film **110** as shown in, for example, FIG. **8**. Namely, the planar size of each of the isolated patterns in the protective film **109** above the peripheral portion of the vibration film **110** may be relatively small, whereas the planar size of each of the isolated patterns in the protective film **109** above the center portion of the vibration film **110** may be relatively large.

[0068] In the above-described example, the pattern densities of the protective film **109** differ between the portion above the peripheral portion of the vibration film **110** and the portion above the center portion of the vibration film **110**. However, the pattern density of the protective film **109** may be configured so as to gradually increase from the portion above the peripheral portion of the vibration film **110** toward the portion above the center portion of the vibration film **110** as shown in, for example, FIG. **9**.

[0069] To summarize, the pattern density of the protective film **109** is configured to be low at the portion above the peripheral portion of the vibration film **110** and high at the portion above the center portion of the vibration film **110**, so that a decrease in sensitivity of the vibration film **110** and an occurrence of creep deformation can be suppressed without causing a decrease in the manufacturing yield of the capacitive micromachined ultrasonic transducer **111**B.

Third Embodiment

[0070] FIG. **10** is a cross-sectional view showing a main part of the capacitive micromachined ultrasonic transducer according to a third embodiment. Note that a planar shape of the capacitive micromachined ultrasonic transducer according to the third embodiment is identical to the planar shape of the capacitive micromachined ultrasonic transducer according to the first embodiment (see FIG. **1**), and thus, illustrations thereof are omitted as appropriate.

[0071] The capacitive micromachined ultrasonic transducer **111**C of the third embodiment differs from the capacitive micromachined ultrasonic transducers **111**A and **111**B of the first and second embodiments in that the thickness of the protective film **109** is not constant. Namely, in the example shown in FIG. **10**, the thickness of the protective film **109** above the peripheral portion of the vibration film **110** is relatively thin, whereas the thickness of the protective film **109** above the center portion of the vibration film **110** is relatively thick.

[0072] Here, effects of the third embodiment will be described. As described in the second embodiment, the occurrence probability of destruction of the vibration film **110** during the mounting step is higher at the center portion of the vibration film **110** than at the peripheral portion of the vibration film **110**. Thus, even if the thickness of the protective film **109** above the peripheral portion of the vibration film **110** is relatively thin, it is considered that there is little influence on destruction of the vibration film **110**. On the other hand, from the viewpoint of suppressing a decrease in sensitivity of the vibration film **110**, it is preferable that the mass of the protective film **109** is reduced. Namely, the thickness of the protective film **109** above the peripheral portion of the vibration film **110** is configured to be relatively thin, so that a decrease in both yield and sensitivity can be suppressed.

[0073] Further, from the viewpoint of creep deformation, the protective film **109** above the peripheral portion of the vibration film **110** has a greater influence on creep deformation than the protective film **109** above the center portion of the vibration film **110** as described in the second embodiment. For this reason, the thickness of the protective film **109** above the peripheral portion of the vibration film **110** is configured to be relatively thin, so that influence on creep deformation can be reduced. In this manner, from the viewpoint of creep deformation, it is preferable that the thickness of the protective film **109** is thinner at the portion above the peripheral portion of the vibration film **110** than at the portion above the center portion of the vibration film **110**.

[0074] In the above-described example, the protective film **109** has two separate thicknesses between the portion above the peripheral portion of the vibration film **110** and the portion above the center portion of the vibration film **110**. However, the thickness of the protective film **109** may be configured so as to gradually decrease from the portion above the center portion of the vibration film **110** toward the portion above the peripheral portion of the vibration film **110** as shown in, for example, FIG. **11**.

[0075] To summarize, the thickness of the protective film **109** is configured to be thin at the portion above the peripheral portion of the vibration film **110** and be thick at the portion above the center portion of the vibration film **110**, so that a decrease in sensitivity of the vibration film **110** and an occurrence of creep deformation can be suppressed without causing a decrease in the manufacturing yield of the capacitive micromachined ultrasonic transducer **111**C.

Fourth Embodiment

[0076] FIG. **12** is a cross-sectional view showing a main part of the capacitive micromachined ultrasonic transducer according to a fourth embodiment. Note that a planar shape of the capacitive micromachined ultrasonic transducer according to the fourth embodiment is identical to the planar shape of the capacitive micromachined ultrasonic transducer according to the first embodiment (see FIG. **1**), and thus, illustrations thereof are omitted as appropriate.

[0077] The capacitive micromachined ultrasonic transducer **111**D of the fourth embodiment differs from the capacitive micromachined ultrasonic transducers **111**A, **111**B and **111**C of the first, second and third embodiments in that the material of the protective film **109** differs between the portion above the peripheral portion of the vibration film **110** and the portion above the center portion of the vibration film **110**. Namely, in the example shown in FIG. **12**, the protective film **109**B above the peripheral portion of the vibration film **110** is made of a material having a lower Young's modulus than a material of the protective film **109**A above the center portion of the vibration film **110**.

[0078] Here, effects of the fourth embodiment will be described. As described in the second embodiment, the occurrence probability of destruction of the vibration film **110** during the mounting step is higher at the center portion of the vibration film **110** than at the peripheral portion of the vibration film **110**. Thus, even if the Young's modulus of the protective film **109**B above the peripheral portion of the vibration film **110** is relatively low, it is considered that there is little influence on destruction of the vibration film **110**. On the other hand, from the viewpoint of suppressing a decrease in sensitivity of the vibration film **110**, it is preferable that

stiffness (=product of Young's modulus and a second moment of cross-sectional area) of the protective film **109** is reduced. Namely, the protective film **109**B above the peripheral portion of the vibration film **110** is made of a material having a relatively low Young's modulus, so that a decrease in both yield and sensitivity can be suppressed.

[0079] Further, from the viewpoint of creep deformation, the protective film **109** above the peripheral portion of the vibration film **110** has a greater influence on creep deformation than the protective film **109** above the center portion of the vibration film **110** as described in the second embodiment. For this reason, the protective film **109**B above the peripheral portion of the vibration film **110** is made of a material having a low Young's modulus, so that creep deformation can be suppressed by reducing stress (=product of Young's modulus and strain) applied to the protective film **109**B. In this manner, from the viewpoint of creep deformation, it is preferable that the Young's modulus of the protective film **109**B above the peripheral portion of the vibration film **110** is lower than the Young's modulus of the protective film **109**A above the center portion of the vibration film **110**.

[0080] In the above-described example, two types of protective films **109**A and **109**B having different Young's moduli are utilized. However, two or more types of protective films having different Young's moduli may be utilized such that the Young's moduli of the protective films are gradually reduced from the portion above the center portion of the vibration film **110** toward the portion above the peripheral portion of the vibration film **110**.

Fifth Embodiment

[0081] FIG. **13** is a perspective view showing an ultrasonic imaging apparatus according to a fifth embodiment. The ultrasonic imaging apparatus **200** of the fifth embodiment has an ultrasonic probe **202**, a display **203**, an operation unit **204**, a signal processor **205** and an ultrasonic transmission circuit **206**.

[0082] The ultrasonic probe **202** is a unit that is brought in contact with a subject and transmits and receives ultrasonic waves to and from the subject. An ultrasonic wave is transmitted from the ultrasonic probe **202** to the subject, and a reflected echo signal from the subject is received by the ultrasonic probe **202**. The ultrasonic probe **202** has a built-in capacitive micromachined ultrasonic transducer **211** electrically connected to the ultrasonic transmission circuit **206**.

[0083] The signal processor **205** is a unit that forms an image (such as a tomographic image or a blood flow image) based on the reflected echo signal. The display **203** is a unit that displays the image. The operation unit **204** is an instruction unit for the ultrasonic imaging apparatus **200** and is constituted by input units such as a keyboard, a trackball, a mouse and the like.

[0084] The ultrasonic imaging apparatus **200** of the fifth embodiment is characterized in that any of the capacitive micromachined ultrasonic transducers **111**A, **111**B, **111**C and **111**D of the first to fourth embodiments is utilized as the capacitive micromachined ultrasonic transducer **211** of the ultrasonic probe **202**, and as a result, an effect in which a highly sensitive ultrasonic imaging apparatus **200** is provided at a low cost can be obtained.

[0085] In the foregoing, the invention made by the present inventors has been concretely described based on the embodiments. However, the present invention is not limited to the foregoing embodiments, and various modifications and alterations can be made within the scope of the present invention.

[0086] For example, the configuration of each of the capacitive micromachined ultrasonic transducers **111**A, **111**B, **111**C and **111**D of the first to fourth embodiments can be combined with each other as appropriate.

LIST OF REFERENCE SIGNS

[0087] **101**: silicon substrate
[0088] **102**: insulating film
[0089] **103**: lower electrode
[0090] **104**: insulating film
[0091] **105**: cavity
[0092] **106**: insulating film
[0093] **107**: upper electrode
[0094] **108**: insulating film
[0095] **109**, **109**A, **109**B: protective film
[0096] **110**: vibration film
[0097] **111**A, **111**B, **111**C, **111**D:capacitive micromachined ultrasonic transducer
[0098] **112**, **113**: foreign matter
[0099] **114**: insulating film
[0100] **115**: gap
[0101] **118**: metal film
[0102] **119**: cavity-forming hole
[0103] **200**: ultrasonic imaging apparatus
[0104] **202**: ultrasonic probe
[0105] **203**: display
[0106] **204**: operation unit
[0107] **205**: signal processor
[0108] **206**: ultrasonic transmission circuit
[0109] **211**: capacitive micromachined ultrasonic transducer

1. A capacitive micromachined ultrasonic transducer comprising:
- a substrate;
- a lower electrode formed on the substrate;
- a cavity formed in a portion of a first insulating film formed over the lower electrode;
- an upper electrode formed on the first insulating film;
- a second insulating film formed over the upper electrode;
- a protective film formed over the second insulating film; and
- a vibration film constituted by the first insulating film, upper electrode and second insulating film above the cavity,
- wherein the protective film above the vibration film is divided into a plurality of patterns arranged with a gap having a predetermined spacing formed therebetween.

2. The capacitive micromachined ultrasonic transducer according to claim **1**,
- wherein a pattern density of the protective film above a peripheral portion of the vibration film is lower than a pattern density of the protective film above a center portion of the vibration film.

3. The capacitive micromachined ultrasonic transducer according to claim **2**,
- wherein a planar size of the protective film above the peripheral portion of the vibration film is smaller than a planar size of the protective film above the center portion of the vibration film.

4. The capacitive micromachined ultrasonic transducer according to claim **2**,

wherein the spacing of the gap in the protective film above the peripheral portion of the vibration film is larger than the spacing of the gap in the protective film above the center portion of the vibration film.

5. The capacitive micromachined ultrasonic transducer according to claim **1**,

wherein a film thickness of the protective film above a peripheral portion of the vibration film is thinner than a film thickness of the protective film above a center portion of the vibration film.

6. The capacitive micromachined ultrasonic transducer according to claim **1**,

wherein a Young's modulus of the protective film above a peripheral portion of the vibration film is lower than a Young's modulus of the protective film above a center portion of the vibration film.

7. An ultrasonic imaging apparatus comprising an ultrasonic probe that includes the capacitive micromachined ultrasonic transducer according to claim **1**.

* * * * *

patsnap

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申请(专利权)人(译)	HITACHI , LTD.		
当前申请(专利权)人(译)	HITACHI , LTD.		
[标]发明人	TAKEZAKI TAIICHI MACHIDA SHUNTARO RYUZAKI DAISUKE YOSHIMURA YASUHIRO NAGATA TATSUYA YAMASHITA NAOAKI		
发明人	TAKEZAKI, TAIICHI MACHIDA, SHUNTARO RYUZAKI, DAISUKE YOSHIMURA, YASUHIRO NAGATA, TATSUYA YAMASHITA, NAOAKI		
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摘要(译)

电容微机械超声换能器包括：硅衬底 在硅衬底上形成的绝缘膜 102 / b> 下电极 103 ;绝缘膜 104 和 106; 空腔 105 由在绝缘膜的一部分中形成的空隙构成; 上电极 107; 绝缘膜 108 和 114; 和保护膜 109。此外，绝缘膜 106，上电极 107，绝缘膜 108 和绝缘膜 114 在腔体上方 105 配置振动膜 110，并将振动膜 110 上方的保护膜 109 定期分成多个隔离图案布置有间隙 115 ，其间形成恒定的间隔。