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**CONDENSER MICROPHONES HAVING
LARGE VALUE BIASING CAPACITORS**

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FIELD OF THE INVENTION

The invention relates generally to condenser microphones having
biasing capacitors and, more particularly, to a condenser microphone having
10 a biasing capacitor for storing a bias charge formed directly on the
microphone backplate or diaphragm to save semiconductor chip space.

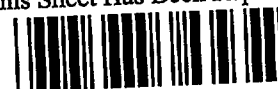
BACKGROUND OF THE INVENTION

A condenser microphone is a capacitive transducer that converts
15 acoustic energy to electrical energy. The sensor typically comprises two
parallel plates of any shape separated by an air gap. One of the plates ("the
diaphragm") is such that it vibrates when sound energy impinges on it, while
the other plate ("the backplate") is built in such a way that it remains rigid.
The backplate includes at least one slot which allows air to flow into and out
20 of the air gap.

The vibration of the diaphragm, with respect to the backplate,
generates a change in the capacitance of the sensor. If a bias charge "Q" is
present on the sensor when the plates are in steady state, then according to
the equation $Q = CV$, the change in the capacitance results in a proportional
25 change in the voltage across the capacitor which conserves the charge.

The condenser microphone has been well established for sound
detection since the beginning of this century. These early microphones
operated with an external direct current (DC) bias applied through a very

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large value resistor. As microphone technology developed, materials that can be permanently charged, called "electrets", were developed. These dielectric materials were placed close to one of the plates (the backplate or diaphragm) of the capacitor, as illustrated in FIG 1. Specifically, FIG 1

5 shows a condenser microphone 5 having an air gap 25 separating a backplate 10 and a diaphragm 15. An electret 20 is coupled to backplate 10 to provide the bias charge to the microphone. Typically, electrets are charged to several hundreds of volts. Microphone 5 would likely be fabricated by machine molding each plate and electret separately and then
10 later assembling the components. Accordingly, such condenser microphones were several tens of millimeters in size having an air gap in the order of hundreds of microns. The bias voltage required to give the required output sensitivity (db) in a microphone depends on the thickness of the air gap. Generally, the smaller the air gap, the smaller the bias voltage required.

15 In the last few years, micro sensor fabrication techniques based on silicon processing have matured. However, such microphones formed on a silicon substrate require an external bias circuit and pre-amplifier for operation. Currently, considerable research is being carried out to fabricate the silicon microphone, the amplifier and the bias circuit on the same
20 semiconductor chip. However, integration of the microphone with circuitry precludes the use of electret material since the process for charging the electrets would destroy the circuits.

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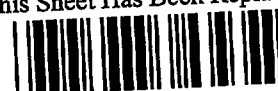


In addition, silicon microphones fabricated using silicon processing have made forming small air gap thicknesses possible. Currently, air gaps are as small as a few microns thick. Since the required bias voltage depends on the thickness of the air gap, a small bias voltage of only a few volts is
5 required to charge a microphone having an air gap only a few microns thick. In such a case, a 1.2 volt battery and a bias generator circuit may deliver all the voltage that is required. In modern silicon microphones, the bias is usually applied through a very large value resistor R_b or through a pre-charged capacitor C_b having a capacitance much larger than the microphone
10 capacitance C_m .

FIG 2A illustrates a schematic of a conventional integrated silicon microphone 30 where the bias is applied through a very large bias resistor R_b . Specifically, microphone 30 comprises a pre-amplifier 35 connected in parallel between bias resistor R_b 40 and a microphone capacitor C_m 45.

15 Further, resistor R_b 40 is connected to bias voltage input V_b 57 and capacitor C_m 45 is connected to ground. On the other hand, FIG 2B illustrates a schematic of a conventional integrated silicon microphone 50 where the bias is applied through a pre-charged bias capacitor C_b . Specifically, microphone 50 comprises a pre-amplifier 55 connected in parallel to very large bias
20 resistor R_b 60 and to a microphone capacitor C_m 65. Further, resistor R_b 40 and capacitor C_b are connected to ground and bias voltage input V_b 67 is connected in series between capacitor C_m 65 and capacitor C_b 70.

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In the device 30 of FIG 2A, a continuous bias voltage supply V_b is required since the charge on the capacitor C_m will leak away through the input resistance of pre-amplifier 35. However, in the device 50 of FIG 2B, once the inner plates of the capacitor C_m are charged, the charge remains for
5 a substantial period of time (e.g., several hours) until it leaks away through various parasitic leakage paths. Note that the charging speed (typically in the 0.01 to 0.1 seconds range) of capacitor C_m is regulated by resistor R_b which eliminates potential voltage spikes.

In addition, the capacitance of bias capacitor C_b should be
10 substantially larger than the capacitance of microphone capacitor C_m . For practical purposes, a bias capacitance 100 times larger than the microphone capacitance is sufficient. For example, if C_m equals 3 pf, then C_b should equal at least 300 pf. Using a typical polysilicon capacitor fabrication process, an area of $500 \times 500 \mu\text{m}^2$ is required for the fabrication of a 300 pf
15 capacitor (at 1.2 fF per μm^2). Of course, for larger microphone capacitances much larger areas are required for the bias capacitor.

Fabrication of a typical microphone using micromachining techniques involves anisotropically etching the silicon substrate by, e.g., electrochemical etching (ECE) using KOH as the etchant. This causes a cavity with sloping
20 walls forming a flat V-shape with the substrate. The silicon real estate above the cavity is usually not used for populating circuitry. Therefore, a large area around the microphone is frequently wasted. Accordingly, it is typical that the bias capacitor encompasses a large area on the chip away from the area above the cavity.



It is therefore an object of the present invention to provide a condenser microphone that retains the charge on the microphone capacitor for a substantial period of time.

Another object of the invention is to provide a condenser microphone
5 which has the bias capacitor formed directly on the backplate to strengthen the backplate.

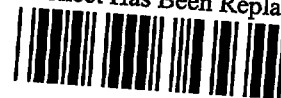
A further object of the invention is to provide a condenser microphone which has the bias capacitor formed directly on the diaphragm or backplate to save chip space.

10 Various other objects, advantages and features of the present invention will become readily apparent from the ensuing detailed description and the novel features which will be particularly pointed out in the appended claims.

15 SUMMARY OF THE INVENTION

These and other objectives are realized the present invention. Specifically, in one embodiment, a microphone sensor is formed on a semiconductor chip. The sensor includes a diaphragm and a backplate, where the backplate is separated from the diaphragm by a predetermined
20 amount to form an air-gap. Further, a biasing capacitor, that stores bias charge, is formed directly on either the diaphragm or the backplate to save chip space.

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In another embodiment, a semiconductor chip, that has an open v-shaped cavity etched from the bottom side of the chip, is described. Such inventive chip includes a sensor, having a diaphragm and a backplate, that is formed above the cavity on the top side of the chip. The chip further a
5 biasing resistor and/or an amplifier which is formed on the top side of the chip. In addition, a biasing capacitor is formed directly on either the diaphragm or preferably on the backplate. The bias capacitor, formed on the microphone diaphragm or preferably the backplate, saves chip space by integrating the bias capacitor with the microphone plates. Further, when the
10 capacitor is formed on the backplate, the design strengthens the backplate against cracking and the like. In addition, no special design is required for the bias capacitor since it automatically scales with the microphone capacitor (since it is formed directly on one of the plates).

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

The following detailed description, giving by way of example and not intended to limit the present invention solely thereto, will best be understood in conjunction with the accompanying drawings in which:

FIG 1 shows a convention microphone having an electret formed on
20 the microphone backplate.

FIG 2A schematically illustrates a conventional integrated silicon microphone 30 where the bias is applied through a very large bias resistor.

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FIG 2B schematically illustrates a conventional integrated silicon microphone 50 where the bias is applied through a pre-charged bias capacitor.

FIG 3A illustrates a parallel plate configuration of a conventional microphone having a metallic backplate.

FIG 3b illustrates a parallel plate configuration of a conventional microphone having a backplate comprising a metallic layer formed on a dielectric layer.

FIG 4A illustrates a parallel plate configuration of a microphone having a bias capacitor, comprised of a metallic layer formed on a dielectric layer, formed on a metallic backplate in accordance with the present invention.

FIG 4B illustrates a parallel plate configuration of a microphone having a bias capacitor, comprised of a metallic layer formed on a dielectric layer, formed on a backplate, comprised of a metallic layer formed on a dielectric layer in accordance with the present invention.

FIG 5A schematically illustrates the microphone diaphragm connected to ground in accordance with the present invention.

FIG 5B schematically illustrates the microphone backplate connected to ground in accordance with the present invention.

FIG 6 shows a microphone, formed on a silicon substrate, having a bias capacitor formed on the microphone backplate and a bias resistor and amplifier formed above a v-shaped cavity region in accordance with the present invention.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIGs 3A and 3B, a conventional microphone structure is illustrated having an air gap separating a diaphragm and a backplate.

Specifically, the microphone of FIG 3A is formed on substrate 85 and includes air gap 88 separating diaphragm 80 from metallic (formed by metallization) backplate 84. Similarly, the microphone of FIG 3B is formed on substrate 95 and includes air gap 98 separating diaphragm 90 from backplate 94. Backplate 94 comprises a metallic layer 92 (e.g., 1 μm thick) formed on a dielectric layer (3 μm thick) 93.

However, since the bottom side of substrates 85 and 95 are etched to form a flat v-shaped cavity (not shown) by, e.g., ECE etching, circuitry (such as a bias resistor or an amplifier) can not be formed above the cavity area.

In the present invention, however, the bias capacitor is formed on the microphone diaphragm or preferably the backplate to save chip space (by integrating the bias capacitor with the microphone plates) and, when formed on the backplate, to strengthen the backplate which prevents cracking. Further, no special design is required for the bias capacitor since it automatically scales with the microphone capacitor (since it is formed directly on one of the plates).

FIG 4A shows a microphone structure having a bias capacitor formed on a metallic backplate. In particular, the microphone of FIG 4A includes air gap 188 separating diaphragm 180 from metallic (preferably formed by metallization) backplate 184. However, unlike the structure of FIG 3A, metallic backplate 184 has a bias capacitor 150 formed thereon. Bias

capacitor 150 comprises a dielectric layer 153 (e.g., 0.3 to 0.5 μm thick) and a metallic layer (e.g., 0.6 to 0.8 μm thick) 152.

FIG 4B shows a microphone structure having a bias capacitor formed on a backplate comprised of a dielectric and a metallic layer. In particular, the microphone of FIG 4B includes air gap 198 separating diaphragm 190 from backplate 194. Backplate 194 includes metallic layer 192 (e.g., 0.8 to 1.0 μm thick) formed on dielectric layer 153 (e.g., 2.5 μm thick). However, unlike the structure of FIG 3B, backplate 194 has bias capacitor 150 formed thereon. As with FIG 4A, bias capacitor 150 comprises a dielectric layer 153 and a metallic layer 152.

FIGs 5A and 5B schematically show how the inventive microphone structure is connected to the pre-amplifier. Specifically, FIG 5A shows a first configuration where the diaphragm 166 is connected to ground, while pre-amplifier 155 is connected in parallel to bias resistor 160 and backplate 164. Note that bias capacitor 170 is coupled to backplate 164. FIG 5B shows a second configuration where the backplate 164 is connected to ground, while pre-amplifier 155 is connected in parallel to bias resistor 160 and diaphragm 166. Note that bias capacitor 170 is coupled to backplate 164.

FIG 6 shows an illustrative section of a semiconductor chip that incorporates a microphone, formed on a silicon substrate over the cavity region. The bias capacitor is formed over the sensor backplate. Moreover,



the bias resistor and amplifier are formed on the top of the chip, connected between the bias capacitor and the sensor diaphragm.

Specifically, a sensor comprising a backplate 194 and an n-well diaphragm 190, separated by an airgap 198 and formed above v-shaped cavity 240, is shown. The n-well region is formed by, e.g., a diffusion of phosphorus. A bias capacitor 150, comprising a dielectric layer 153 and a metallic layer 152, is formed on a metallic layer 192 of backplate 194. Backplate 194 also comprises a dielectric layer 193, formed on plasma enhanced oxide pads 215. Diaphragm 190 includes a plurality of slots 40, while backplate 194 and capacitor 150 include a plurality of acoustic holes 205.

Oxide pads 215 are formed on a plasma enhanced nitride layer 220, which is formed over an inter layer dielectric 220 and field oxide regions 230. Between two of the field oxide regions 230 is an n+ region (formed by, e.g., arsenic diffusion) that connects the diaphragm to bias resistor 260, amplifier 255, and output voltage V_o via metal interconnect pad 235 (preferably formed of aluminum). Capacitor 150 is also connected to resistor 260 and amplifier 255, while backplate 194 is connected to bias voltage V_b .

While several embodiments have been chosen to illustrate the invention, it will be understood by those skilled in the art that various changes and modifications can be made herein without departing from the scope or spirit of the invention as defined in the appended claims.

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WHAT IS CLAIMED IS:

1. A sensor formed on a semiconductor chip, comprising:
a diaphragm;
a backplate separated from said diaphragm by a predetermined
5 amount to form an air-gap; and
a biasing capacitor for storing bias charge formed directly on one of
said diaphragm and said backplate to save chip space.
2. The sensor of claim 1, wherein said biasing capacitor includes a
10 dielectric layer and a conductor layer.
3. The sensor of claim 2, wherein said biasing capacitor is formed
on said backplate, and wherein said backplate includes a second dielectric
layer and a second conductor layer.
15
4. The sensor of claim 3, wherein said first and second conductor
layers are metallic formed by metallization.
5. The sensor of claim 4, wherein said second dielectric layer of
20 said backplate is nitride and said second conductor layer of said backplate is
aluminum.

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6. The sensor of claim 2, wherein said biasing capacitor is formed on said backplate, and wherein said backplate includes a second conductor layer.

5 7. The sensor of claim 6, wherein said first and second conductor layers are metallic formed by metallization.

8. The sensor of claim 7, wherein said first and second conductor layers are aluminum.

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9. The sensor of claim 1 further comprising an amplifier connected to said backplate, wherein said diaphragm is connected to ground.

10. The sensor of claim 1 further comprising an amplifier connected
15 to said diaphragm, wherein said backplate is connected to ground.

11. The method of fabricating a sensor on a semiconductor chip, comprising the steps of:

forming a diaphragm on or in said chip;

20 forming a backplate over said diaphragm such that an air-gap of a predetermined depth is formed between said diaphragm and said backplate; and

forming a biasing capacitor directly on one of said backplate and said diaphragm to save chip space.





12. The method of claim 11, wherein said step of forming a biasing capacitor includes forming a conductor layer on a dielectric layer.

13. The method of claim 12, wherein said step of forming a biasing
5 capacitor forms said biasing capacitor on said backplate, and wherein said step of forming a backplate includes forming a second conductor layer on a second dielectric layer.

14. The method of claim 13, wherein said first and second
10 conductor layers are metallic formed by metallization.

15. The method of claim 14, wherein said second dielectric layer of said backplate is nitride and said second conductor layer of said backplate is aluminum.

16. The method of claim 12, wherein said step of forming a biasing capacitor forms said biasing capacitor on said backplate, and wherein said step of forming a backplate includes forming a second conductor layer.

17. The method of claim 16, wherein said first and second
20 conductor layers are metallic formed by metallization.

18. The method of claim 17, wherein said first and second conductor layers are aluminum.

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19. The method of claim 11 further comprising the steps of:

connecting an amplifier to said backplate; and

connecting said diaphragm to ground.

5 20. The method of claim 11 further comprising the steps of:

connecting an amplifier to said diaphragm; and

connecting said backplate to ground.

21. A semiconductor chip having an open v-shaped cavity etched

10 from the bottom side of the chip, comprising:

a sensor, having a diaphragm and a backplate, formed above said
cavity on the top side of said chip;

at least one of a biasing resistor and an amplifier formed on said top
side of said chip; and

15 a biasing capacitor formed directly on said backplate to save chip
space and to strengthen said backplate.

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