MEMS based Condenser Microphone

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ABSTRACT

This paper presents study and analytical result of condenser microphone and proposes a structure that can be finalized by using MEMS (Micro Electro-Mechanical System) technology. The microphone using a thin silicon crystalline material of flexible diaphragm and gold material fixed Back Plate. The aim of this paper is to develop high sensitive microphone with high capacitance at low fabrication cost. The microphone is fabricated using bulk micromachining. By using equivalent circuit model, we have calculated resonant frequency, capacitance, sensitivity and pull-in voltage. The microphone has a diaphragm thickness of 25 μm, of square shaped diaphragm of area of 5mm^2, air gap of 55 μm and back plate thickness of 1mm. A 3V bias voltage is applied to the microphone. The sensitivity of more than 4.8 μV/Pa with a Pull-in voltage of more than 30V.

Keywords: MEMS, Condenser Microphone, Structure of Microphone, Equivalent circuit diagram, Sensitivity and Pull-in Voltage.

1. INRODUCTION

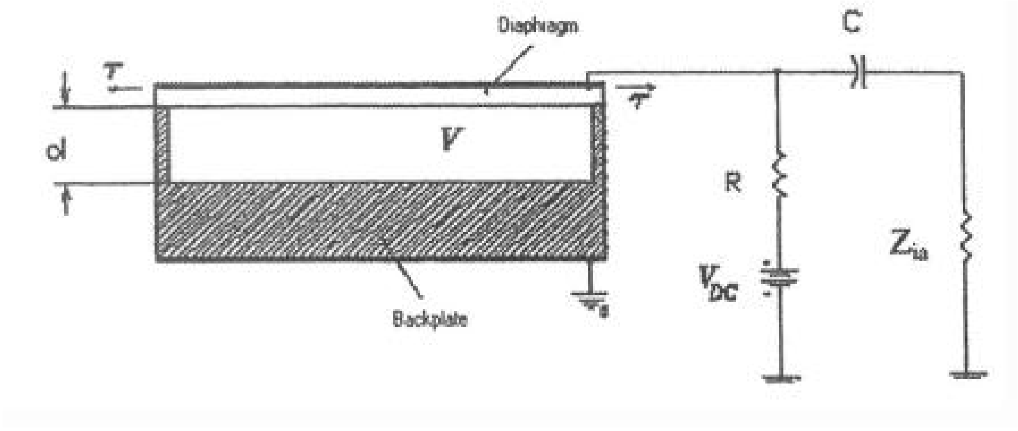
MICROPHONES are transducer that converts acoustic energy into electrical energy. The microphones are widely used in voice communications, hearing aids, noise, and vibration control [1]. The micromachining technology has been used to design and fabricate various silicon microphones. The silicon microphones have been based on the piezoelectric, pizoresistive and capacitive principles [2].

A piezoelectric microphone consists of a very thin diaphragm but it has a disadvantage of having relatively high noise level [3]. A piezoresistive microphone consists of a diaphragm which having four piezo-resistors used in a Wheat-stone bridge configuration. An advantage of the piezoresistive microphone is the relatively low output impedance [3]. Out of these there, Capacitive microphones shows highest sensitivity at low power consumption. Diaphragms can be made of metal, p+ doped silicon, silicon nitride, polyimide [4, 7]. The most successful devices use silicon as the diaphragm material because of its low intrinsic stress. This stress in microphone is very important because it determines the diaphragm sensitivity and its resistance. The use of MEMS microphones has increased due to some factors.[3] like: surface mount capability, integration of signal processing capability and low susceptibility to acceleration effects.[5] MEMS microphone that can be assembled using high volume surface mount techniques, standard low cost, would provide a cost saving of system [5].

In this paper, a condenser microphone is studied, we use p type silicon of thin membrane, with gold coating on glass back plate. This design using thin silicon diaphragm to increase sensitivity of condenser microphone. With the help of equivalent circuit, we have calculated sensitivity and pull-in voltage.

2. STRUCTURE OF MICROPHONE

Condenser Microphones generally consist of a diaphragm that is vibrated by impinging waves of acoustic pressure, a back plate and air gap. In its simplest form, a diaphragm is placed over a conducting back plate and supported by copper wire so that a gap between the membrane and the back plate is formed [6]. Fig. 1 shows the basic structure of the condenser microphone. A diaphragm having a tensile force, T, is put in front of a fixed conducting back plate which separated by a distance, d. An acoustic wave cause vibration to the diaphragm so that, the distance from the back plate changes. The change of distance will produce a change in capacitance, varying voltage, V, on the electrodes.



This structure works as a condenser whose capacitance is given as:

$$C = \frac{\varepsilon o.A}{d}. \tag{1}$$

where o is the dielectric constant of the air and *A* is the surface area of the diaphragm.

3. EQUIVALENT CIRCUIT MODEL OF MICROPHONE

The performance of the microphone depends on the size and stress of the diaphragm. Other parameters, such as air gap distance and the bias voltage, also affect the sensitivity. In Figure 2,

Fsound = acoustic force,

Vm = flow velocity of air

Rr = air radiative resistance

Mr = air mass

Mm = diaphragm mechanical mass

Cm = diaphragm compliance.

Ca = air gap compliance

Rg and Rh are losses of viscous resistances.

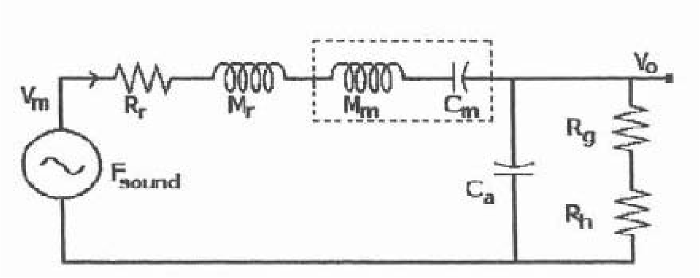


Fig2. Equivalent circuit of MEMS based Condenser Microphone.

The diaphragm compliance depends on its flexural rigidity, D, and tension, T. The flexural rigidity of the diaphragm is given [7] by:

$$D = \frac{Et^3}{12(1-v)} . \tag{2}$$

Where, E = Young's modulus of elasticity,

t = diaphragm thickness

v = Poisson's ratio.

The tension, T, is calculated is given as:

$$T = t.\sigma_r . \tag{3}$$

Where, σ_r = residual stress of diaphragm material Resonant frequency for the diaphragm:

$$f = \frac{1}{\rho} \; \overline{\frac{D\pi^2}{a^4} + \frac{T}{2a^2}}.$$

Where a = diaphragm edge width.

ρ

= density of material using in membrane.

$$R_r = \frac{\rho_0 a^4 \omega^4}{2\pi c}.$$

$$M_r = \frac{8\rho_0 a^3}{3\pi\sqrt{\pi}}. \qquad (5) \text{ and } (6)$$

Where ρ_0 = air density,
c = velocity of sound
ω = the angular frequency (2 πf).

The diaphragm compliance is equal to the average diaphragm deflection divided by the applied force. Compliance is given as:

$$C_m = \frac{32a^2}{\pi^6(2\pi^2 D + a^2 T)}. \qquad (7)$$

The mass element, Mm is given by:

$$M_m = \frac{\pi^2 \rho (2\pi^2 D + a^2 T)}{64T}. \qquad (8)$$

The air gap viscosity loss, Rg, and its compliance, Ca, are given by[7]:

$$R_g = \frac{12\eta a^2}{n d^3 \pi} \; \frac{\alpha}{2} - \frac{a^2}{8} - \frac{ln\alpha}{4} - \frac{3}{8} \; .$$

$$C_a = \frac{d}{\rho_o c^2 \alpha^2 a^2}.$$

(9) and (10)

Here, n = hole density in the back plate
α= surface area,
η = air viscosity coefficient
d = average distance
ρ_0= air density.

Zt is the total equivalent impedance of the circuit shown in Fig 2 and is given by:

$$Z_t = R_r + j\omega \; M_r + M_m \; + \frac{1}{j\omega C_m} + \frac{R_g+R_h}{1+j\omega \; R_g+R_h \; C_a}. \qquad (11)$$

The sensitivity of the microphone is a function of the frequency. Optimization:

Our goal is to design the maximization of sensitivity. The principal design variables are: diaphragm size a, the diaphragm thickness t, the back plate thickness h, the air gap thickness d.

At low frequencies, the sensitivity of the microphone can be approximated as:

$$S_o = \frac{32V_b a^4}{\pi^6 T_d}. \qquad (12)$$

The pull-in voltage for square elastic plate under tension is given by:

$$V_p = \frac{64}{7} \sqrt{\frac{2}{45}} \sqrt{\frac{Td^3}{\varepsilon_0 a^2}}. \qquad (13)$$

This equation satisfies only when t<0.01a. The sensitivity can beexpressed in terms of the pull-in voltage and bias-voltage as:

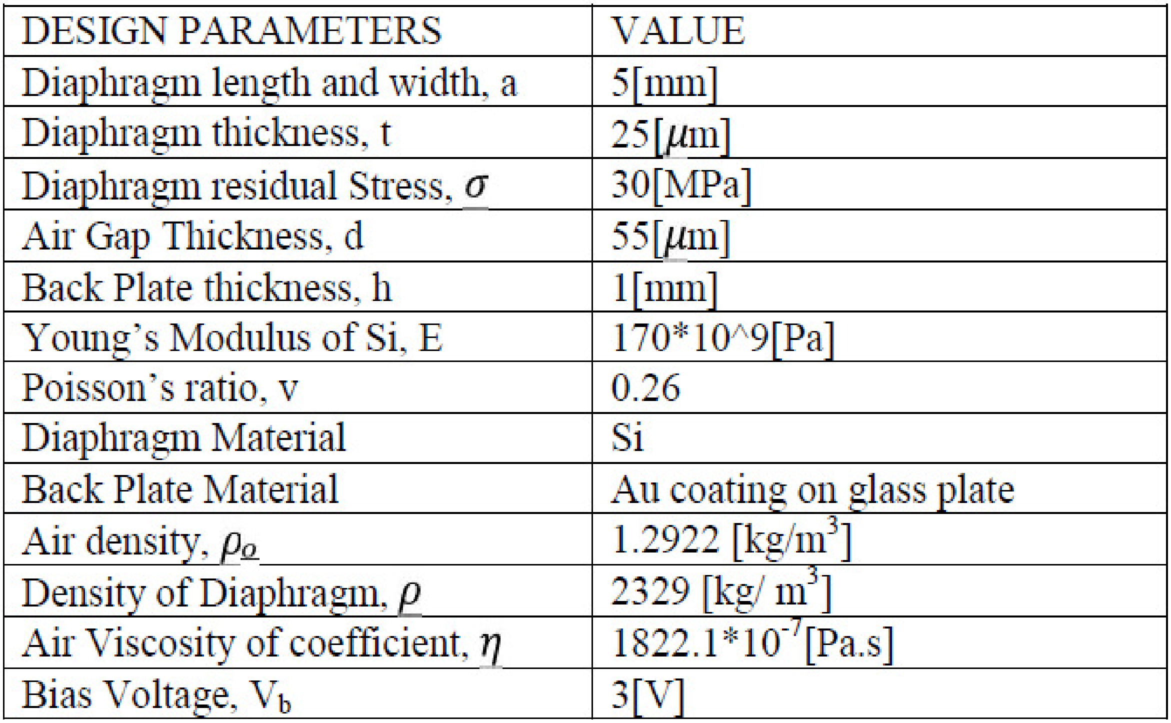
$$S_o = \frac{0.12366}{\varepsilon_o} \frac{V_b}{V_p^2} \; d^2. \qquad (14)$$

Now, Vp can be expressed as in terms of C as:

$$V_p = \frac{64}{7} \overline{\frac{2}{45}} \overline{\frac{Td^2}{C}}. \quad (15)$$

4. RESULTS AND DISCUSSION

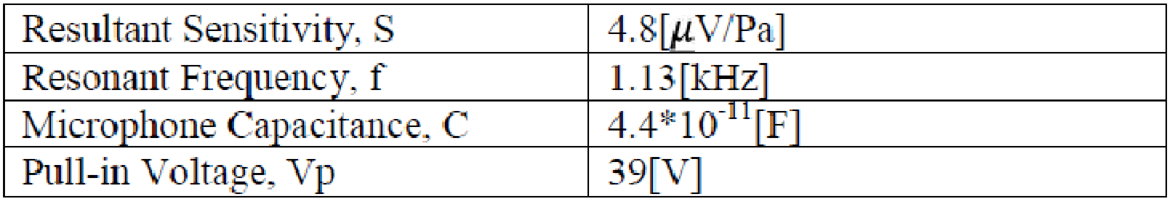
Table 1: Design parameters and value of Condenser Microphone is using.



DESIGN PARAMETERS	VALUE
Diaphragm length and width, a	5[mm]
Diaphragm thickness, t	25[μm]
Diaphragm residual Stress, σ	30[MPa]
Air Gap Thickness, d	55[μm]
Back Plate thickness, h	1[mm]
Young's Modulus of Si, E	170*10^9[Pa]
Poisson's ratio, v	0.26
Diaphragm Material	Si
Back Plate Material	Au coating on glass plate
Air density, ρ_o	1.2922 [kg/m^3]
Density of Diaphragm, ρ	2329 [kg/ m^3]
Air Viscosity of coefficient, η	1822.1*10^{-7}[Pa.s]
Bias Voltage, V_b	3[V]

Output

Table 2: Value of sensitivity, resonant frequency, capacitance and pull-in voltage of Condenser Microphone.



Resultant Sensitivity, S	4.8[μV/Pa]
Resonant Frequency, f	1.13[kHz]
Microphone Capacitance, C	4.4*10^{-11}[F]
Pull-in Voltage, Vp	39[V]

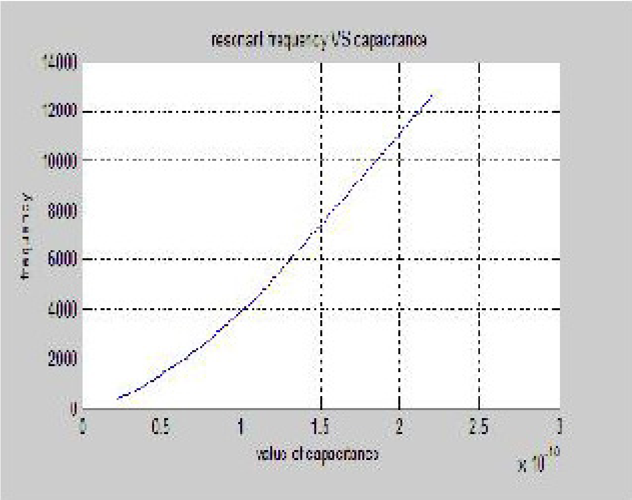


Fig 3. Shows the linear relation between the resonant frequency and value of capacitance at different air gap.

Fig. 4 shows the change in capacitance at different air gap between plates. Capacitance decreases when air gap increases.

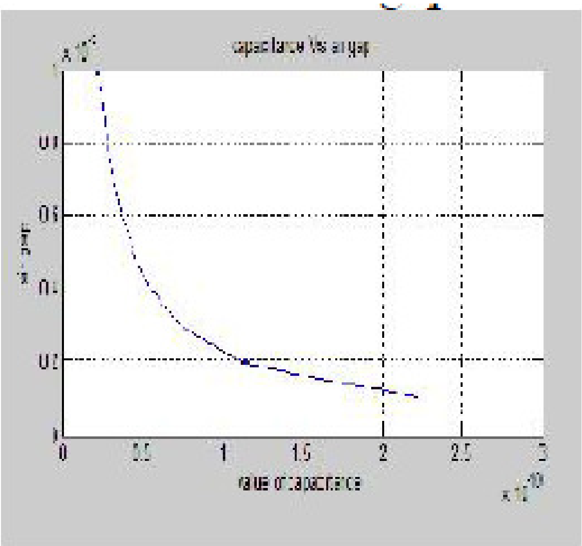


Fig 4. This graph shows relation between capacitance and air gap between two plates.

Fig 5. shows relation between sensitivity and frequency response. For a particular value of sensitivity the frequency response is become constant, as shown in graph.

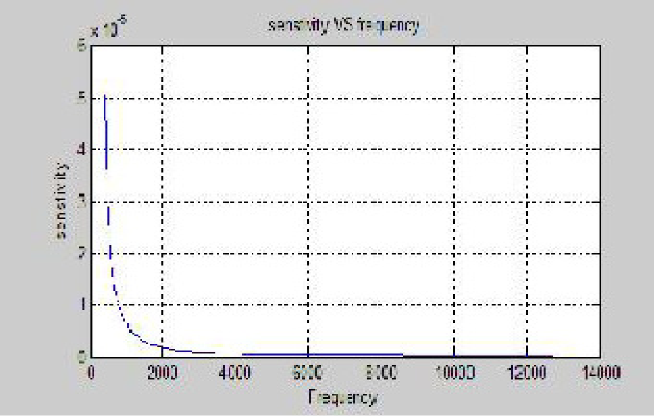


Fig 5. This graph shows relation between sensitivity and resonant frequency.

Fig 6. shows the relation between sensitivity and pull-in voltage. Increasing the sensitivity also increases the value of pull-in voltage.

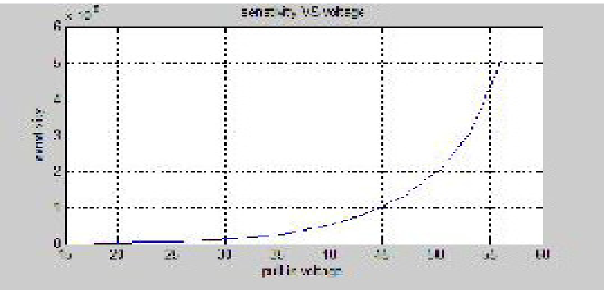


Fig 6. This graph shows relation between sensitivity and pull-in voltage.

Fig 7, shows linear relation between pull-in voltage and air gap. Pullin voltage is increases by varying the distance between plates.

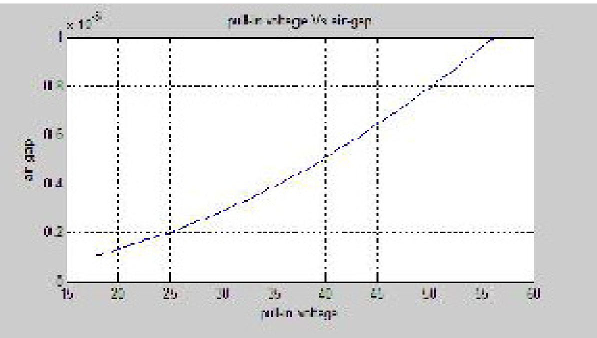


Fig 7. This graph shows relation between pull-in voltage and air gap between plates.

5. CONCLUSION

The analysis of sensitivity and pull-in voltage of condenser microphone is presented in this paper. This paper using Si material as membrane and simple gold back plate without holes. According to the result, the microphone with a 5mm diaphragm width and 25 m thickness, it resulted a sensitivity of 4.8μV/Pa. We have seen that there is no hole and slots in back plate, comparatively less sensitivity comes out, measured pull-in voltage is 39V. Losses at high frequencies, due to the compression of air in the air gap, can be minimized by providing holes or acoustical ports in the back plate. It is also possible to increase the bias voltage until the electrostatic force between the diaphragm and the back plate is so large that the diaphragm collapses.

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