

MEMS BIO-VIBRATION SENSOR

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ABSTRACT

A MEMS based vibration sensor for Bio-application (especially pulse sensing and stethoscope) is reported. In our design, a nitride cantilever beam is used as moving part in the device. Piezoresistive sensing technique is adopted to detect the deformation of the nitride beam under vibration. The optimal design is obtained after analyzing the dynamic response of the device system.

Keywords: Vibration sensor, Piezoresistivity, Dynamic analysis

INTRODUCTION

Blood pressure is one of the most frequently measured parameters in clinical practice and cardiovascular research. The blood pressure pulse, originating at the heart, is modified as it travels through the vasculature, due to elastic and geometric nonuniformities in the arterial system. In addition to systolic and diastolic blood pressures, the waveform of the pressure pulse provides valuable information on the elastic properties of the vessels in the propagation path. [1]

The doctor of Western medicine believe that some significant parameters relevant to the cardiovascular system can be derived from the pulse waveform, while the doctor of traditional Chinese medicine, even further, uses pulse feeling as his fundamental means of diagnosis, holding the opinion that pulse conditions reveal essential information concerning man's state of health.

Nowadays, researchers generally follow two distinctive approaches in the research of pulse sensing technique. The first one is to develop a sophisticated robot system which incorporates a skin-like tactile sensing array with a dexterous finger manipulated by a hierarchical control system. The other approach is to develop comparatively simple yet much more practical means for pulse sensing, which aims at the acquisition of as much physiological data as possible through pulse monitoring with the aid of convenient devices based on present-day technology. Recently, the most popular devices for pulse measurement are photoelectric pulse pickups. When employing photoelectric pickups, an important consideration is the amount of heat produced by the exciter lamp. Heat causes dilatation of blood vessels, hence alter the state of the vascular bed under examination.[2]

We developed the MEMS based vibration sensor is small in size and compatible in IC circuit. It can be batch fabricated. Also due to small dimension of the MEMS sensor, the force to drive (vibrate) the sensor can be relatively small and the sensitivity can be increased. Besides the small size and high sensitivity, the MEMS Bio-vibration sensor (MBVS) also can avoid the heat produced by exciter lamp which causes dilatation of blood vessels. In addition, the marketing of the pulse sensor had approximately \$1.3 billion in 1997.[3]

SYSTEM DESIGN

Based on the introduction of application in the pulse sensing, our device should work in the frequency ranging from several Hertz to hundred Hertz. There are several ways to

sensing a vibration, such as: piezoresistive, piezoelectric, capacitive sensing, optical sensing, tunneling tip, and resonant detection. It is obvious that some techniques like tunneling tip are not suitable for our application.

A membrane in shown in Fig 1 can be used as sensing part in our device.

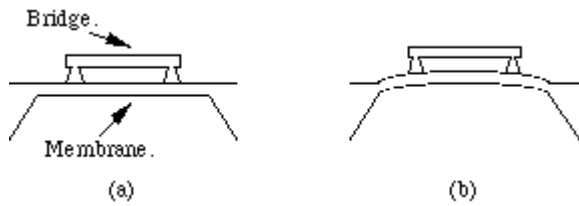


Figure 1: Membrane vibration

The membrane in MEMS is usually very thin. It should be protected in practical use. While in our application, the device is directly contact with human body, it will be challenging to make interface between the sensing membrane and human body to avoid the breaking of the thin membrane.

In order to make the device robust, the fragile MEMS parts should be protected. In AXDL accelerometer, the sensing signal is got from capacitance change between moving comb finger and non-moving comb fingers. At the same time, the whole MEMS parts are packaged in a robust shield. Our design adopts this idea; we will sense relative deformation (i.e. the relative position) of a cantilever beam. Due to elastic properties of the cantilever beam, when the whole device vibrates with pulse vibration, the cantilever beam will bend more or less compared to the substrate.

Fig 2 schematically shows the design of our device; we use polysilicon as sensing materials, silicon nitride as structure beam, electroplated nickel as proof mass.

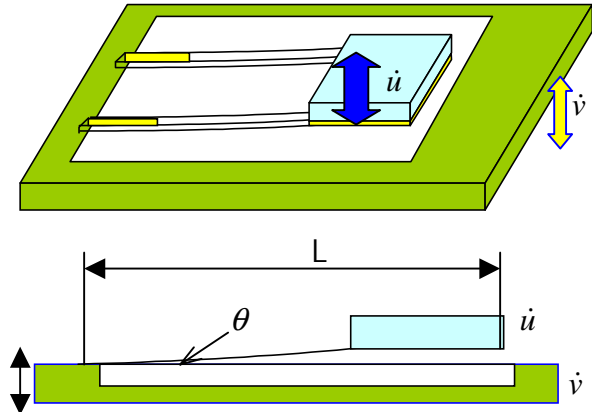


Figure 2: Schematic concept of vibration sensor

In the following part, the analysis of frequency response for our device will be carried out. Based on the analysis result, we will get the optimal geometry dimension of the cantilever beam and proof mass for our device in bio-application.

DYNAMIC ANALYSIS

When the sensor in the Fig 2 is vibrating upwards, the nickel proof mass exerts a force that bends the nitride beam, at the same time, the air damping contributes beam vibration. The deflection of the nitride beams changes the dimension of resistors R_b and R_c and their resistance value (piezoresistors). In our design, we choose piezoresistive sensing because it is easy to obtain and fabricate piezoresistive materials, like polysilicon in regular MEMS process. By running a current through these resistors, which are also part of a Wheatstone Bridge circuit, as shown in Fig.3, we can easily determine the amount of deflection. [4]

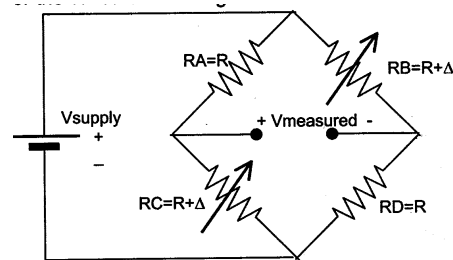


Figure 3: Wheatstone Bridge circuit

$$V_m = V_s \times \left(\frac{R_c(R_d + R_b) - R_d(R_c + R_a)}{(R_a + R_c)(R_b + R_d)} \right) \quad (1)$$

$$R_a = R_d, R_b = R_c$$

$$V_m = V_s \times \left(\frac{R_b - R_a}{R_a + R_b} \right) = V_s \times \left(\frac{\frac{\Delta R}{R}}{2 + \frac{\Delta R}{R}} \right) \quad (2)$$

$$\frac{\Delta R}{R} \approx 2 \frac{V_m}{V_s} \quad (3)$$

$$\frac{\Delta R}{R} = k_{poly} \varepsilon \quad (4)$$

Where k_{poly} is a factor for the polysilicon piezoresistivity.

Assuming the beams bend a little bit to form a circular arc:

$$\varepsilon = \frac{H\theta}{2L} \quad (5)$$

From (3), (4), and (5), we can get:

$$V_m = \frac{k_{poly} H V_s}{4L} \theta \quad (6)$$

From the bending geometry, we can get:

$$\theta = \frac{u - v}{L} \quad (7)$$

From (6) (7) we have:

$$V_m = \frac{k_{poly} H V_s}{4L^2} (u - v) \quad (8)$$

Consider the forces on the proof mass, (force for mass acceleration, cantilever restoring force, and air damping) we have

$$m_{proof} \ddot{u} = -k_{cantilever} (u - v) - b\dot{u} = -\frac{EWH^3}{4L^3} (u - v) - b\dot{u} \quad (9)$$

$$\text{Let: } \dot{u} = w \quad (10)$$

We can get:

$$\begin{bmatrix} \dot{w} \\ \dot{u} \end{bmatrix} = \begin{bmatrix} -\frac{b}{m_{proof}} & -\frac{EWH^3}{4L^3 m_{proof}} \\ 1 & 0 \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix} + \begin{bmatrix} \frac{EWH^3}{4L^3 m_{proof}} \\ 0 \end{bmatrix} v \quad (11)$$

$$V_m = \begin{bmatrix} 0 & \frac{V_s k_{poly} H}{4L^2} \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix} + \frac{V_s k_{poly} H}{4L^2} \cdot v \quad (12)$$

In eqn (11) (12), v is the displacement of the whole device, which is the same as the pulse vibration in our case. V_m is the measured voltage we can get from Wheatstone Bridge. W, H, L is the width, thickness and length of nitride beam. m_{proof} is proof mass of electroplated nickel.

SYSTEM SIMULATION

In according to the above analysis, we have the following design.

$L=100 \mu\text{m}$, $H=1 \mu\text{m}$, $W=5 \mu\text{m}$, $b=0.5 \text{ N}\cdot\text{s}/\text{m}$, $Pl=100 \mu\text{m}$, $Pw=100 \mu\text{m}$, $Ph=11 \mu\text{m}$, $V_s=10 \text{ Volt}$, $\rho = 8.9 \times 10^3 \text{ kg}/\text{m}^3$

The step response, signal response and frequency response are shown in Figure 4, Figure 5 and Figure 6 respectively

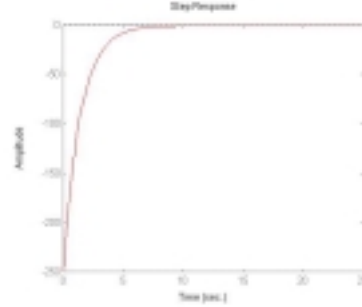


Figure 4. Step Response

Assume vibration signal: $V(\text{mm})$

$$0.01\sin(2\pi \times 1 \times t) + 0.002\sin(2\pi \times 10 \times t)$$

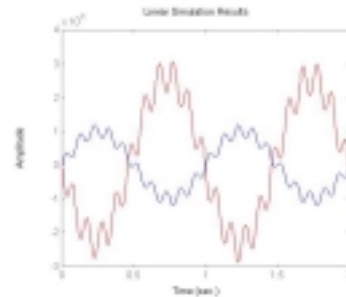


Figure 5: Output Time Response (red line) vs. Input Time Response (blue line)

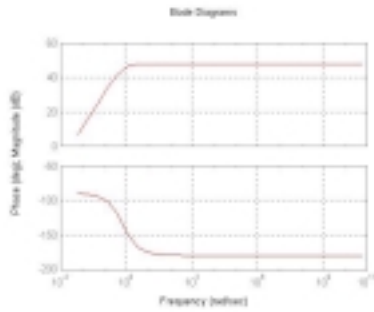


Figure 6: Bode Diagram for Output Voltage (Frequency Response of Magnitude and Phase)

The transfer function is

$$\frac{-250S^2 - 1.27 \times 10^{11} S}{S^2 + 5.107 \times 10^8 S + 3.575 \times 10^8}$$

The poles are -5.1×10^8 ; the other is close to 0. And the zero are 0, -5.1×10^8 . In fact, the compliance of beam is very critical for the system response. For example, if the length of beam (L) is reduced to 10 μm , then the step response

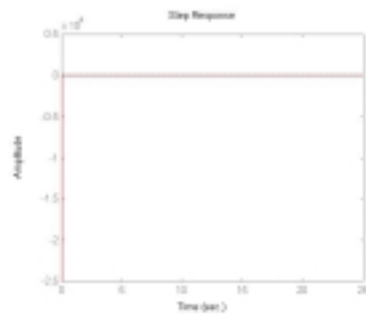


Figure 7: Step Response (L=10 μm)

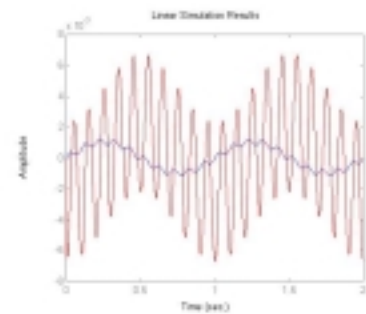


Figure 8: Time Response (L=10 μm)

Figure 9: Bode Diagram for Output Voltage (L=10 μm)

CONCLUSION

A MEMS-based vibration sensor was developed due to the variety of biology application such as blood pressure, stethoscope and personal health diagnosis. A simple cantilever beam combined with piezoresistive sense technology was the basic idea in the device. In the analysis, we find the compliance of cantilever beam plays an important role on system performance. By optimally designing the dimension of cantilever beam and proof of mass, we can achieve low frequency, low distortion and high sensitive response that meet the requirement on bio-application.

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