Study On Artificial Hair MEMS As Flow Cell Sensors Application

Mohd Afzan Sharom, S. M. Firdaus, Ishak Abd Azid

Abstract: This paper presents the mechanical modelling and finite elements analysis (FEA) based on cantilever and artificial hair cell MEMS as flow sensors. The structure of this biomimetic flow sensor consists of a single cylindrical hair cell which is perpendicular to a cantilever length of 10000µm. The Sensor performance is measured by the distribution of Stress occurrence and displacement. In order to study the sensor force of 0.02N represent gas flow the force which is applied to cylindrical hair cell variation of the width of cantilever and height of the cylindrical hair cell. The FEA result shows the highest stress occurred as the width of the cantilever decrease while the displacement increase also when the width of cantilever decrease.

Key words: Flow Sensor, Cantilever, Micro-electro-mechanical-system (MEMS), Stress, Artificial Hair Cell

1 INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a silicon substrate through the utilization of microfabrication technology [1, 2]. Flow sensors have attracted much attention due to their various applications such as controlling supply air in air conditioning systems [3] and injecting quantities needed in automotive applications [4]. Development of flow sensor had been done by past researcherers based on various physical principles like momentum(mechanics), Doppler effect (acoustic), heatconduction (thermodynamics), pressure difference (hydrodynamics), conductivity (electrodynamics) and nuclear resonance (nuclear physics) [5]. Development of sensors based on cantilever is the simplest device among MEMS device and it has a bright future for the development sensors for novel physical, chemical and biological applications[6]. In order to sense physical fluid flow the piezoresistive doped to silicon cantilever. Gas flow rate was measure by analysis the output from strain gauge that attached to the root of the cantilever beam. Meanwhile the sensor fabrication process was straightforward, $20ms^{-1}$ flow rate the maximum measurable flow rate had been recorded.[7] Animals hair cells that respond to movements of a surrounding medium are the mechanoreceptors commonly found in creatures like crickets.

- Mohd Afzan Sharom is currently pursuing masters degree program in mechanical engineering in University Technology MARA, 13500 Penang, Malaysia. E-mail: afzansharom@hotmail.com
- S.M. Firdaus is Research lecturer in mechanical engineering in University Technology MARA, 13500 Penang, Malaysia.
E-mail: sh.firdaus@ppinang.uitm.edu.my
- IshakAbdAzid is Professor in mechanical engineering in University Science of Malaysia, 11400 Penang, Malaysia. E-mail: ishak@eng.usm.my

The spider-cricket's escape behaviour is by exploiting the air motion using 10s-100s of filiform hairs, space with small separations distances to notice their predators movement [8]. Mimicking biological systems is executed in many ways such as 'stealing' sensor principles, morphological designs, materials properties, behaviour or any combination of these from nature. However, the main challenge is to efficiently exploit the lessons learned from nature into engineered technologies. Computational models nowadays play an important role to behave precisely like the MEMS devices which are to be developed. The advantages of simulation is that it enables the behaviour of the MEMS devices to be predicted quickly [9]. This FEA aspect regarding cantilever is based on stress distribution and displacement measurement, meanwhile materials of cantilever is silicon elastic anisotropy. The external load force parallel to the cantilever and normal to vertical hair cell. Due to the rigid connection between the horizontal cantilever and the vertical hair cell, a mechanical bending moment is transferred to the cantilever as a result of the cantilever stresson top of cantilever surface. With a different dimension of cantilever it will have a difference stress distribution on top of the cantilever surface. An artificial haircell will use numerical analysis (FEA) approach that originated from mechanical engineering to predict mechanical responses to load. The common overview of a hair cell comprise of a filiform hair attracted to a neuron and if this neuron is bent by fluid flow, it produces output reaction. Hair in crickets consist of two large mechano- sensory hair arrays, called cerci, residing at the crickets' rear body, form the sensing part of a cricket's escape mechanism [8]. Each cercus is covered with up to a few hundred mechanoreceptive hair sensors with varying geometric and mechanical properties such as length, diameter and rotational stiffness. Each filiform hair has an elongated paraboloid shape which varies between 30 and 1500 µm in length and 1 to 10 µm in base diameter [10]. Figure 1 illustrates the basic structure of the cercal sensory system found in crickets' skin.

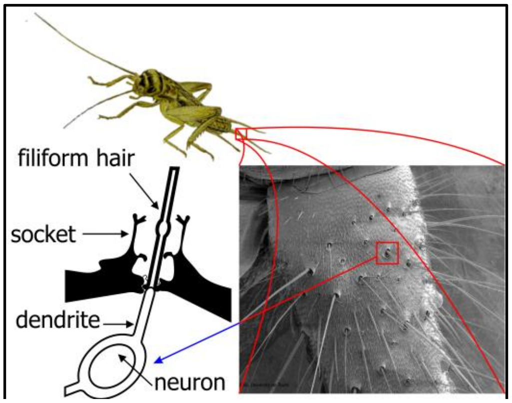


Figure 1. Basic structure mechnosensory system of crickets[11]

2 METHODOLOGY

This section presents an overview of the developments of artificial hair flow- sensor. Sensor modelling consists of rectangular horizontal cantilever with filiform hair attached at the free end (Fig. 2). When the external load force or pressure is applied to the filiform hair due to the rigid connection between the horizontal cantilever and the filiform hair, a mechanical bending moment is transferred to the horizontal cantilever, inducing the strain and stress. Basically piezoresisitive will be doped at top of the cantilever surface, piezoresistive effect will sense the stress of the hair cell and change into electrical signal [12]. Maximum deflection occurs during force implementing for cantilever has constant cross section which can be computed by applying equation (1) [13].

$$\delta_{max} = \frac{Fl^3}{3EI} \qquad (1)$$

δ_{max} is the maximum deflection, F is force loaded, l is the length of cantilever, E is a Young's Modulus of material where in this research is a silicon is $1.124 \times 10^{11}\ Nm^{-2}$ and I is a cantilever moment inertia. Figure 2 presents the schematic diagram sensor deflection where it has one fixed end and one free end with force/pressure implemented.

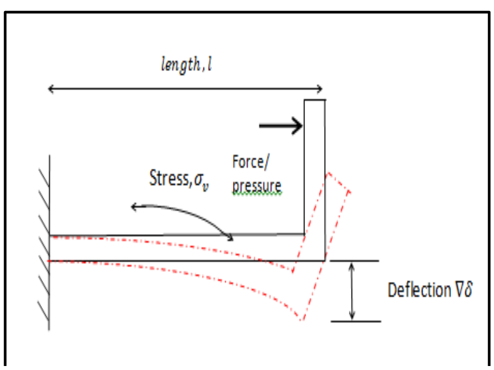


Figure 2.Schematic diagram of the artificial hair cell deflection.

Maximum stress, σ_{max} can be computed using equation (2) for constant cross section cantilever.

$$\sigma_{max} = \frac{6Fl}{bh^2} \qquad (2)$$

Parameter $F$is force, l is length of the cantilever, b is the width and h is the thickness [14] The FEM model is studied by manipulating its dimensions ofcantilever (Figure 3). The model is treated as a solid body with material properties like silicon linear elastic isotropic. Results were obtained after the distribution of stress subsequent to implementing the force to the top cantilever surface.

3 RESULT AND DISCUSSION

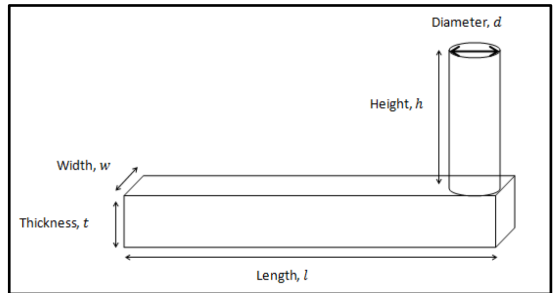
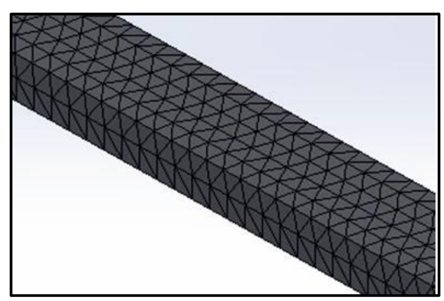


Figure 3.Model dimension of the Sensor

The horizontal cantilever was fixed with size of thicknessand length of 500µm and 10 000µm respectively. The heights of thecylindrical hair cell are 1000µm, 2000µm, 3000µm, 4000µm, and 5000µm respectively, and the diameter follows the width of the cantilever, $w = d$. Meanwhile, the dimensions of the cantilever width are 500 μm, 1000 μm, 1500 μm, $2000 \mu m$, 2500 μm respectively. The model is treated as a solid body with material properties of silicon linear elastic isotropic. For finite element analysis (FEA) to generate mesh for hair cell, it proposed to analyse the stress distribution and structure deformation due to load force applied figure 4(b) show the stress on the top cantilever surface. In mesh generations, triangular elements cells are selected by the mesh free method (Mfree)[15]. Figure 4(a) show the mesh generation for sensor model.

(a)



(b)

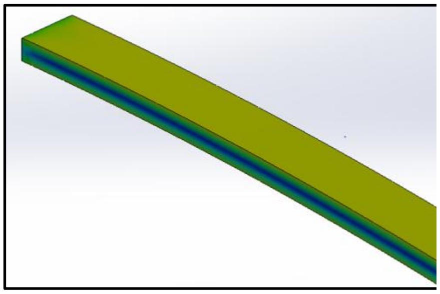
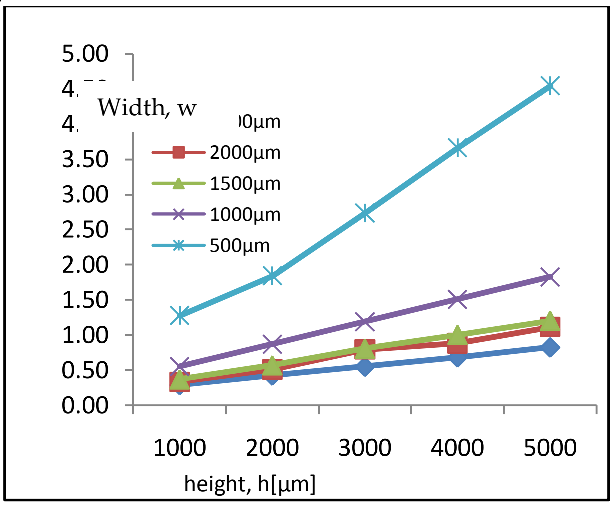


Figure 4. (a)Mesh model for cantilever hair cell : (b) The Static Nodal Stress distribution on top cantilever surface

(a)



(b)

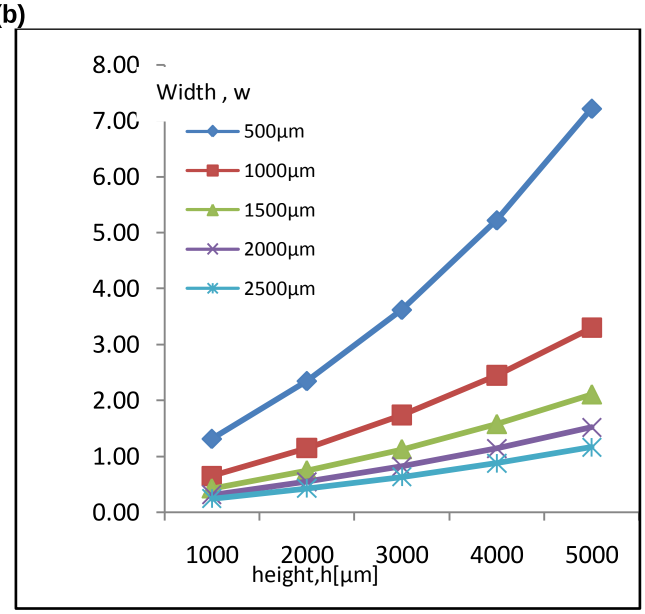


Figure 5 (a)FEA sensor output for stress distribution on top cantilever surface ; (b) FEA output for sensor displacement.

The bio-inspired flow sensor with 500µm width and hair cell $5000\mu m$ heigth has the highest stress value which was $4.55 Mpa$. Meanwhile dimension of 2500µm width and hair cell 1000µm height provided the lowest stress value of $0.29 Mpa$. As expected from the formula, thestress (σ) value is inversely proportional with the width(w) size of cantilever. From plotted graph**5(a)** and **5(b)** output measurement of stress and displacement directly proportional to height of hair cell. When width size of cantilever decrease value of stress on top surface area cantilever will increase and when height of hair cell increase the stress on top surface area cantilever also increase.Figure **5(a)** shows the plotted graph for the stress distribution with different cantilever width size and height of hair cell.

4 Conclusion

The study of the bio-inspired flow sensor using the finite element analysis has proved that different dimensions of hair cell sensor gives a significant cause to the stress distribution and displacement of cantilever. MEMS-based air flow sensor featuring a free standing micro-cantilever, in sensing operations such as cantilever deform due to the air velocity, the resistance value will change. The change of resistance value is due to the piezoresistance layer whichwas deposited on top of the cantilever surface. The highest performance of the sensor was accomplished by sensor dimension (500x500x10000)μm and height $5000\mu m$ respectively.

5 ACKNOWLEDGMENT

The author wish to thank University Technology MARA for the Excellent Grant (600-RMI/ST/Dana5/3/Dst(113/2011) and Government of Malaysia for Fundamental Research Grant Scheme (FRGS) 600-RMI/FRGS 5/3(39/2012) that have enable this research to be carried out.

6 REFERENCES

[1]. T. W. Lim,Y. Song, D. Y. Yang, H. J. Kong, K. S. Lee, S. H. Park, "Highly effective three-dimensional large-scale microfabrication using a continuous scanning method," Applied Physics A: Materials Science & Processing, vol. 92, pp. 541-545, 2008.

[2]. C. Y. Lee,Y.H. Wang, T. H. Hsueh, R. H. Ma, L. M. Fu,P. C. Chou,"A smart flow sensor for flow direction measurement," Advanced Materials Research, vol. 47, pp. 189-192, 2008.

[3]. M. Shikida, K. Yoshikawa, S. Iwani, K. Sato, "Flexible flow sensor for large-scale air-conditioning network systems," Sensors and Actuators A: Physical, 2011.

[4]. U. Schmid, "A robust flow sensor for high pressure automotive applications," Sensors and Actuators A: Physical, vol. 97, pp. 253-263, 2002.

[5]. N. Nguyen, "Micromachined flow sensors--a review," Flow measurement and Instrumentation, vol. 8, pp. 7-16, 1997.

[6]. J. Brugger, M. Despont, C. Rossel, H. Rothuizen, "Microfabricated ultrasensitive piezoresistive cantilevers for torque magnetometry," Sensors and Actuators A: Physical, vol. 73, pp. 235-242, 1999.

[7]. Y. Su, AGR. Evans, A. Brunnschweiler, G. Ensell, "Characterization of a highly sensitive ultra-thin piezoresistive silicon cantilever probe and its application in gas flow velocity sensing," Journal of Micromechanics and Microengineering, vol. 12, p. 780, 2002.

[8]. T. Shimozawa, T. Kumagi, Y. Baba, "Structural scaling and functional design of the cercal wind-receptor hairs of cricket," Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, vol. 183, pp. 171-186, 1998.

[9]. M. Madou, "Fundamentals of microfabrication. 1997," CRC Press LLC. Capítulo, vol. 1, pp. 1-50.

[10]. T. Shimozawa, Masamichi, "The aerodynamics and sensory physiology of range fractionation in the cereal filiform sensilla of the cricketGryllus bimaculatus," Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, vol. 155, pp. 495-505, 1984.

[11]. O. Dangles,C. Magal, D. Pierre, A. Olivier, J. Casas, "Variation in morphology and performance of predator-sensing system in wild cricket populations," The Journal of experimental biology, vol. 208, pp. 461-468, 2005.

[12]. Q. Zhang,W. Ruan, H. Wang, Y. Zhou, Z. Wang, L. Liu, "A self-bended piezoresistive microcantilever flow sensor for low flow rate measurement," Sensors and Actuators A: Physical, vol. 158, pp. 273-279, 2010.

[13]. P. Benham, R. Crawford, C. Armstrong, "Mechanics of engineering materials, 1996," Harlow Longman Group.

[14]. E. Finot, A. Passian, T. Thundat, "Measurement of mechanical properties of cantilever shaped materials," Sensors, vol. 8, pp. 3497-3541, 2008.

[15]. G.-R. Liu, Mesh free methods: moving beyond the finite element method: CRC, 2009.