Comb Finger Capacitive Micro Wind Sensor

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ABSTRACT

This paper reports a novel micro wind sensor with comb finger shaped structure based on MEMS technology and capacitive sensing principle, which can measure wind speed and direction simultaneously. The proposed sensor was theoretically analyzed based on fluid mechanics theory and simulated by FEA software ANSYS. The fabrication processes based on Si-Glass anodic bonding and DRIE technology were designed and experiments were carried out to research how sensor structure released. The sensor was fabricated with the size of 1cm×1cm and packaged on a PCB board and tested in a wind tunnel. The test result shows that the sensor can realize wind speed measurement and is sensitive to wind direction.

Keywords: MEMS, micro wind sensor, comb finger structure, capacitive

1 INTRODUCTION

Wind speed is one of the most important parameters in meteorological observation. The micro wind sensor based MEMS technology was reported in many papers, because it has many advantages such as small size, light weight, low cost and high sensitivity. For example, F. Mailly reported an anemometer with hot platinum thin film based thermal sensing principle [1]. Yu-Jen Fang designed a novel differential hot wire anemometers with two different post CMOS fabrication process based on the same principle[2]. Lidong Du reported a micro solid state silicon plate wind velocity sensor based drag force principle and detected with sensing resistor[3]. The thermal sensing elements have high sensitivity at low wind speed, but the drag force is reversed. This paper will show a completely different wind sensor with comb structure, capacitive measurement principle, and it can measure wind speed and direction simultaneously based on the pressure drag with sensing capacitors.

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2 STRUCTURE AND PRINCIPLE

The traditional wind sensor generally has two sensing elements, the wind cups for wind speed measurement and a vane for wind direction measurement. The micro wind sensor will integrated the two elements into one chip. It is important for its structure design and principle innovation. The integrated micto wind sensor has many advantages that it is not only decreasing the size but can measure the wind in real time.

2.1 Structure Design

A schematic view of the micro comb wind sensor is shown in Figure 1, with a 3D structure(a), top view(b) and side glance(c), in which the label 1 to 8 indicates the glass substrate, airflow drag body, fixed interdigital, isolated finger, movable interdigital, cross support structure and pad respectively.

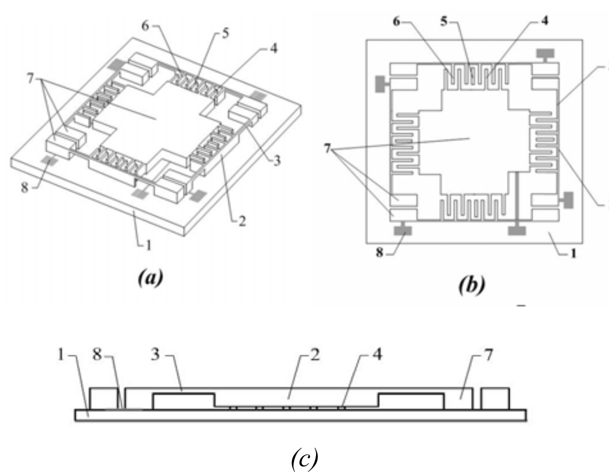

Figure 1: Micro comb wind sensor structure: (a)3D structure,(b) top view and (c) side view.

2.2 Principle

The sensor work principle is shown in fig.2. the movable and fixed interdigital fingers form a changeable capacitance when the wind blow to airflow drag body.

According to the basic formula for parallel plate capacitor, there is :

$$c_0 = \frac{\varepsilon S}{d_0} \quad (1)$$

where the S is the effective area of the relative opposite fingers and d_0 is the distance between the them. Supposing that there are N fingers on each side of the sensor, the capacitance is given as:

$$C_0 = Nc_0 + C_p = N\frac{\varepsilon S}{d_0} + C_p \qquad (2)$$

where C_p is the total stray capacitance due to complex structure. When the wind blow to the drag body, it will be brought to a drag force F_d:

$$F_d = K_D \frac{\rho A_d}{2} v^2 \sin^2\theta \qquad (3)$$

where K_D is drag flow resistance coefficient, ρ is air density, v is wind speed, θ is angle of wind direction showing in fig. 2 and A_d is the area of face the wind.

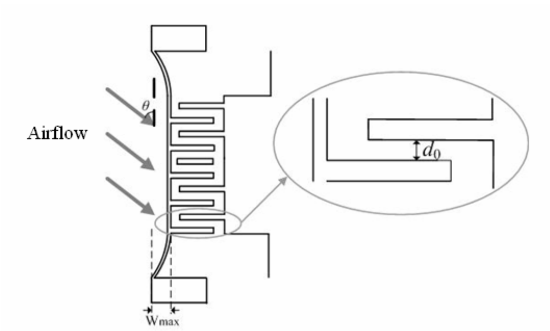

Figure 2: capacitive principle of the micro comb wind sensor

According to the deflection of cantilever elasticity formula, the maximum deflection of the support beam can be found as:

$$w_{\max} = \frac{4L_d^{\ 3}}{Eh_d t_d^{\ 3}} F \qquad (4)$$

where L_d is the lenth of support beam, E is Young's modulus of silicon, h_d and t_d are the height and width of the beam respectively.

According to the formula (3) and (4), the maximum deflection of support beam is found as following:

$$W_{\max} = \frac{2K_D\rho L_d^{\ 3}}{Eh_d t_d^{\ 3}} A_d v^2 \sin^2\theta \qquad (5)$$

Due to the drag body including movable interdigital fingers do not bend deformation, it will move a distance $W_{\max}$ along the wind direction. When the angle is in the range of 0°～90°, the capacitance is written by:

$$C = Nc_0 + N\frac{\varepsilon h_D w_{\max}}{d_0} + C_p = N\frac{\varepsilon h_D w_{\max}}{d_0} + C_0 \qquad (6)$$

Considering the wind speed and direction and sensing principle, the integrated micro wind equivalent circuit described in Figure 3, C1, C2, C3 and C4 are a sequence of orthogonal capacitors in four quadrants and suppose the capacitance C1 corresponding to the west direction, C2 to south, C3 to the east and C4 to the north.

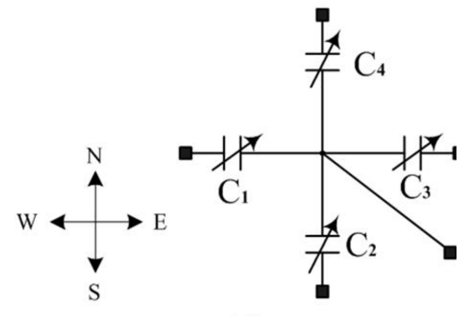

Fig. 3: Equivalent circuit of the sensor.

Therefore when the wind blows to the drag body from certain direction, there are two capacitors that will change. The variations of the output capacitor are as following:

$$\begin{cases} \Delta Ci = N\dfrac{2K_D\rho\varepsilon h_D l_d^{\ 3}}{Ed_0 h_d t_d^{\ 3}} A_d v^2 \sin^2\theta \\ \Delta Cj = N\dfrac{2K_D\rho\varepsilon h_D l_d^{\ 3}}{Ed_0 h_d t_d^{\ 3}} A_d v^2 \cos^2\theta \end{cases} \qquad (7)$$

When the wind angle is in the range of 0°～90°, the i=1 and j=4, in the range of 90°～180°, the i=1 and j=2, in the range of 180°～270°, i=2 and j=3, and in the range of 270°～360°, i=3 and j=4.

Define a constant M,

$$M = N\frac{2K_D\rho\varepsilon h_D l_d^{\ 3}}{Ed_0 h_d t_d^{\ 3}} A_d \qquad (8)$$

M is a constant that is related with the sensor's structure and size, also with the materials and air perperties. From formula (7) and (8), it can be explained that the sensor's capacitance change only conrespondes to the wind speed v and deirection θ. When the wind direction angle θ is constant, the output capacitance variation is a quadratic function of wind speed v. When wind speed v is constant, the change in the output capacitor is a quadratic function of the sine or cosine of the wind angle θ.

By measuring the capacitor C1, C2, C3 and C4 changes both the directions of east and west, north and south can be gotten respectively,

$$\begin{cases} v_{ew} = v \sin\theta \\ v_{ns} = v \cos\theta \end{cases} \quad (9)$$

Combining the two speeds the real wind speed u and angle θ are found as:

$$u = \sqrt{u_{ns}^{\ 2} + u_{ew}^{\ 2}} \quad (10)$$

$$\theta = (Q-1)\frac{\pi}{2} + \arctan(u_{ns} / u_{ew}) \quad (11)$$

where Q is the quadrant of sensor (Q=1, 2, 3 and 4). When calculating the wind direction, first according to the change of Ci (i=1, 2, 3 and 4) determine the quadrant Q, than from formula (11) get the angle.

2.3 Finite Element Analysis

Finite element analysis (FEA) is a powerful analysis technology. In fluid–structure interaction, fluid flow exerts pressure on a solid structure, which causes it to deform.

Selecting one quadrant of he micro sensor for finite element analysis. The size of drag body is 2000μm in length, 40μm in width and 100μm in height. The size of movable finger is 300μm in length, 20μm in width and 100μm in height. The loads for all directions on the boundary displacement are zero, that is one end of a fixed support beam to a different direction angle to impose uniform pressure load facing the airflow at the surface.

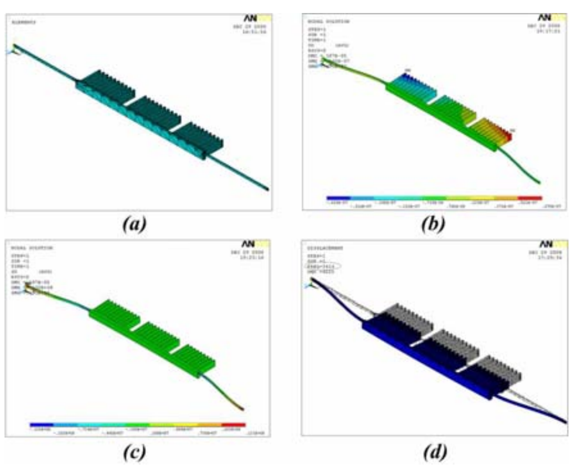

Fig. 4: simulation results with FEA

Figure 4 shows the simulation results with FEA to a set of inerdigital. (a) is gridded finite element model including a support beam, drag body and movable fingers. The other parts did not include for their unmovable properties. (b) is the distribution of deflection when the air pressure (wind speed at 5m/s, direction angle 90°) applied to the support beam and (c) represents the distribution of stress. The stress is greatest focus on supporting beam root. In addition, a first resonant frequency was simulated in consideration of which related to the dynamic response of the sensor. The result shows in Figure 4(d). Table 1 shows the first resonant frequency of five support beams with different structures.

	1	2	3	4	5
Inherent frequency	3414	4889	2516	2735	4718

Table 1. First resonance frequency of five beams with different structure

3 FABRICATION

The fabrication process for the sensor is shown in Figure 5 including nine steps.

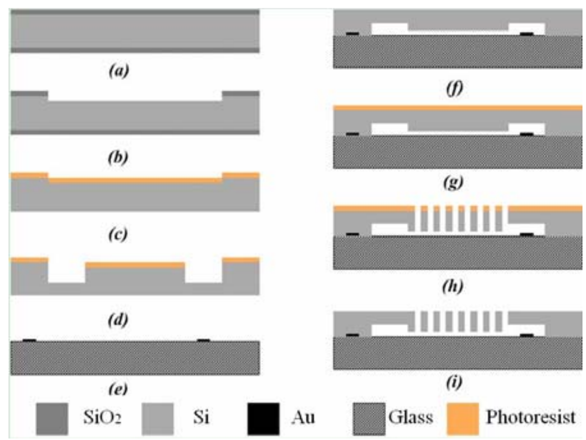

Figure 5:Fabrication process

The process is as following. In the first step, a (100)-oriented, silicon wafer deposited nitride film by LPCVD wafer is selected (figure 5(a)). The silicon nitride is etched by RIE and wet etching to form a 10μm groove (b). Then a photoresist layer is spun on the silicon wafer (c). Patterning the gap between the support beam and glass, the 70μm grooves is formed by DRIE (d). The electrodes and pads is patterned and deposited on a glass (e). Next with the anodic bonding technology, the prepared silicon wafer and glass stick together and then with the wet etching technology to thin the silicon wafer to left about 110μm (f). Next spinning the photoresist and patterning (g), the comb structure is released by DRIE on front (h). Wiping off the photoresist (i) and slice the wafer, the micro comb wind sensor has been fabricated.

4 RESULTS AND DISCUSSIONS

The sensor chip has been implemented according the design and the simulation.Figure 6 shows the final device with partial enlarges under the optical microscope. The sensor was packaged on a PCB and measured in a small wind tunnel.

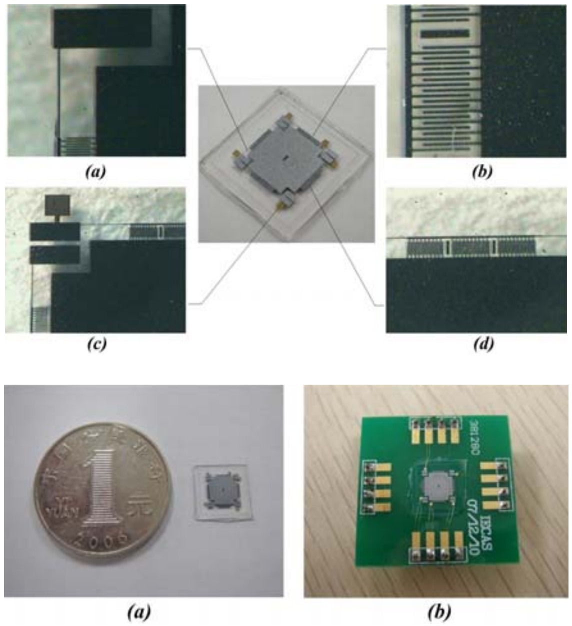

Figure 6:Optical microscope of the sensor and the PCB package

Since the restriction on the test instrument, adopted a fixed wind speed testing methods, only the adjacent capacitors C1 and C2 orthogonal have been tested. When C1 is facing to the wind direction, the relationship between C1 and wind velocity is a quadratic function as shown in Figure 7. The maximum wind speed for this sensor reaches to 12m/s .

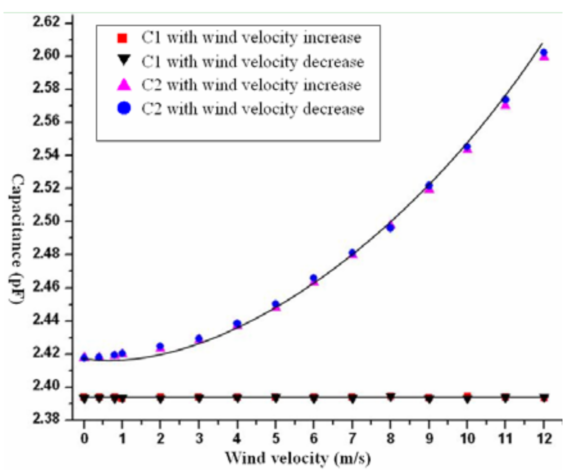

Figure 7: relationship of capacitance changed with wind speed

The wind direction measurement test also in the tunnel. The wind sensor was rotated manually. The change of capacitance C1 follows with rotating. The front is exerted the drag force and the back side is viscous friction. Figure 8 shows the detail test results.

5 CONCLUSION

Based on the FEA, a micro wind sensor chip has been designed and with the micoelectromechanical system technology the device has been fabricated successfully. The wind speed and direction has been meassured with the sensor in a small wind tunnel and its function realized. The sensor has several advantages compared with hot wire wind sensor, no thermal conductive, radiation and convections effect, wide range with different support beam size, easy to compensation etc. However there's a long way to go toward as a usful sensor.

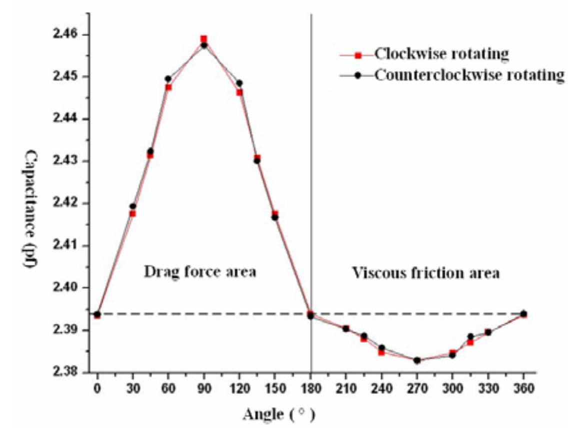

Figure 8: relationship of capacitance changed with the wind blew angle

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