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A More Reliable and Easy Manufacturing Wireless Thermal Convection Angular Accelerometer without any Movable Parts and Grooved Cavity

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Abstract: Five novel ideas are proposed in this paper to integrate an active RFID tag with a thermal convection angular accelerometer on a flexible substrate, thus the device is a wireless sensor. The first innovative idea is that this device is made directly on a flexible substrate without any movable parts and grooved cavity, so it is very easy to make and reliable. The second new idea is that the flexible substrate is plastic or polyimide, the thermal conductivity of the flexible substrate is much lower than the traditional silicon, and thus it can save more power and very useful for mobile operation. The third new idea is that the inert xenon gas is filled in the chamber to conduct the heat instead of CO_2 used in the traditional thermal convection accelerometer. Carbon dioxide can produce oxidation effect to the heater and thermal sensors, while the Xe gas will not. The fourth new idea is to apply a hemi-spherical chamber; it is more streamline in nature with less drag effect. Thus it can ease the fluid flow and yield quicker response. The fifth new idea is the most powerful one to integrate the angular accelerometer with an active RFID tag on the same flexible substrate, thus the device becomes a more useful wireless angular acceleration sensor. In this paper we only use the hemi-spherical chamber filled with Xe gas. The sensitivity is 258°C/(rad/s^2) and the response time is 81μs.

Keywords: Angular accelerometer, RFID tag, flexible substrate, grooved cavity, thermal convection, hemi-spherical chamber, xenon gas

1. Introduction

Conventional accelerometers are made on silicon wafers, some of them used the thermal convection technologies, and the chamber is filled with air, CO_2, liquid, or others [1,29]. As shown in Fig. 1 five novel ideas are proposed to integrate an active RFID tag with thermal convection angular accelerometers on a flexible substrate, thus the device can become a wireless sensor. The first innovative idea is that the new device is made directly on a flexible substrate without any movable parts and grooved cavity, so it is very easy to make and reliable. The second new idea is that it is made on a flexible substrate as plastic or polyimide, the thermal conductivity of the polyimide (0.06-0.0017 W/(cm-K)) is about twenty-fifth of the silicon (1.48 W/(cm-K)), thus it can save more power and very useful for mobile operation. The third new idea is to use inert xenon gas in the chamber for heat convection instead of the previous CO_2, which can produce oxidation effect to the heater and thermal sensors [1,29], while the

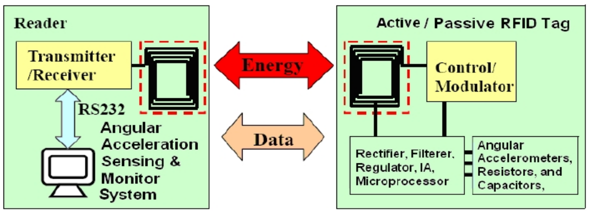

Figure 1 Block diagram of the proposed RFID-based angular accelerometer.

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xenon gas will not. So the heater reliability can be increased. The fourth new idea is to apply a hemi-spherical chamber; it is more streamline in nature with less drag effect. Thus it can ease the fluid flow and yield quicker response. Besides, the Xe molecular weight (131.29 g/mol) is three times of CO_2 (44.01 g/mol), so the inertia is larger and can also yield quicker time response. Thus both the device sensitivity and bandwidth are larger than the traditional packages by using rectangular chamber [18]. The outer case of the new device can still use the rectangular one for easy marking part name and series number. The fifth new idea is the most powerful one to integrate an active RFID tag with the angular accelerometer on the same flexible substrate, thus the device becomes a more useful wireless sensor, that can be applied in the fields of hospital monitoring, game, etc., so the new device is very easy for usage and fabrication. The deposited heater is made by chromium (Cr) and nickel (Ni), and its operating temperature is 127°C (400K) without melting the polyimide substrate. In this paper we only use the hemi-spherical chamber filled with Xe gas. The sensitivity is $258°C/(rad/s^2)$ and the response time is $81\mu s$. The paper organization is as follows: the first section is the introduction. The next concerns fabrication and packaging steps. The third one is simulation and discussion. Finally, a summary is given.

2. Fabrication and Packaging Steps

Step 1: Deposit SiO_2 on both sides of substrate for thermal, electrical and humidity isolation. Cover Photo Resist (PR) on both sides to protect SiO_2. The result is in Fig.2.

Figure 2 The result of design Step 1.

Step 2: Deposit p-type amorphous silicon with thickness 100-250 μm, then using an Nd-YAG laser to anneal it as a poly-silicon thermister. The next is to use mask 1 and Photo-lihtography And Etching Processes (PAEP) to reserve the PR on the poly-silicon thermister. Finally, use KOH solution or RIE process to remove the layers of poly-silicon without PR protection. After removing the PR, the result is in Fig.3.

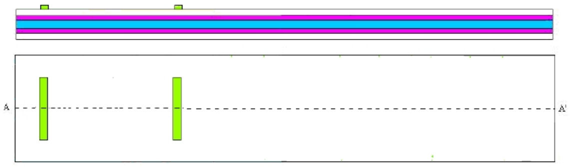

Figure 3 The result of design Step 2.

Step 3: Deposit Cr and Ni to make the heater, and the supporting layers of RFID antenna, and conductors connected to the power supply. The next is to use mask 2 and PAEP to reserve the PR on the heater, RFID antenna, as well as the conductors connected to the power supply. Finally, use sulfuric acid solution or RIE process to remove the layers of Cr and Ni without PR protection. After remove the PR, the result is in Fig.4. Note that the temperature sensors can also be made by the E-beam evaporation process by using anyone set of the deposited thermal pile materials as follows: K-type (Chromel and Alumel), J-type (Iron and Constantan), E-type (Chromel and Constantan) and T-type (Copper and Constantan).

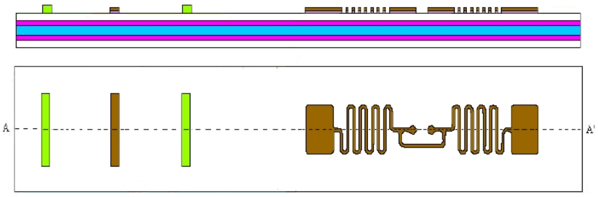

Figure 4 The result of design Step 3.

Step 4: Use mask 3 and PAEP to reserve PR on the heater, and flash a layer of gold on Ni by electroless-plating. Thus the conductivity of the RFID antenna, and the conductors connected to the power supply would be very good. In addition, the performance of the soldering process on the pads for packaging would also be increased. Then remove the PR. The result is in Fig.5.

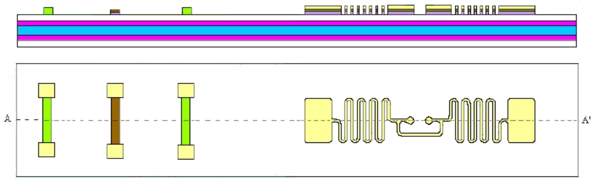

Figure 5 The result of design Step 4.

Step 5: Using screen printing method to put plastic or polymer material as the sealing material around the accelerometer as dam bar as in Fig.6,

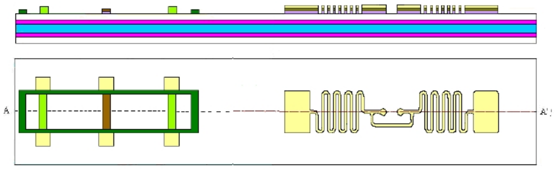

Figure 6 The result of design Step 5.

Step 6: The chip with metal bump is flip chip bonded to RFID feed terminal by thermal compression method, and then make the underfill to increase the adherence of chip. Finally, put a cap with hemi-spherical shaped internal chamber on the dam bar, before curing and sealing it one can fill it with the proposed xenon gas, and the result is in Fig.7. For comparison, the traditional squared internal chamber is as in Fig.8.

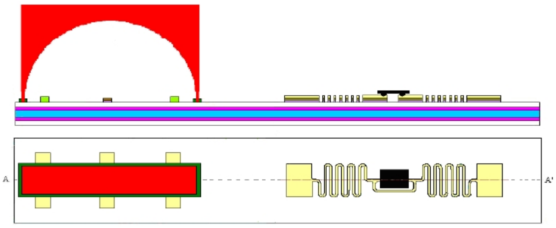

Figure 7 The result of design Step 6.

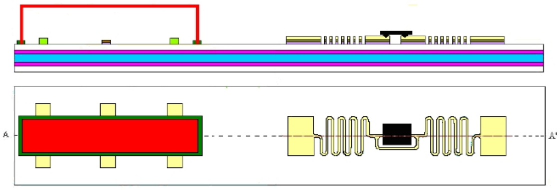

Figure 8 Traditional squared internal chamber.

Step 7: To increase the sensitivity, reduce the bias effects due to fabrication and layout errors, as well as compensate the common mode rejection ratio, make four angular accelerometers in a full differential Wheatstone bridge. Finally, put both a socket and a spring to fix the battery on the substrate, the active RFID sensor is as shown in Fig.9.

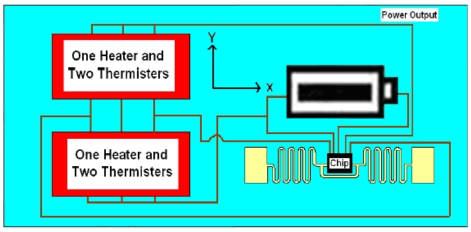

Figure 9 The result of Step 7.

3. Simulation and Discussion

In this section we use ESI-CFD+ software package for 3D simulation. Firstly, the geometric definitions of heater, thermistors and hemi-spherical chamber dimensions are defined as in Fig.10, in which H=19.7mm, W1=2mm, S= 2mm, and W2=0.3mm. The temperatures of the package boundaries and the heaters are set as 300K and 400K, respectively. The thermal sensors can be put at any one of the three points as in Fig.10 to be trade-off later. The governing equations of mass, momentum, and energy are respectively as follows:

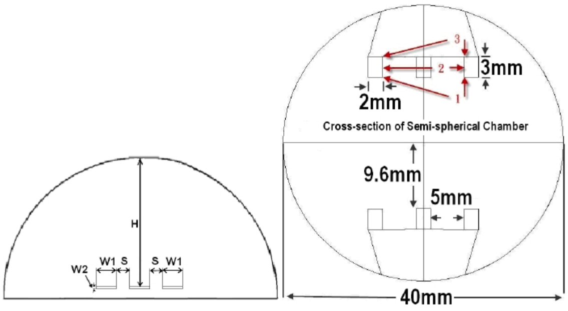

Figure 10 Geometric dimensions of heater, thermistors and hemi-spherical chamber.

$$\nabla \bullet \bar{u} = 0 \tag{1}$$

$$\frac{\partial \rho}{\partial t} + \nabla \rho \bar{u} = 0 \tag{2}$$

$$\frac{\partial\rho\bar{u}}{\partial t}+\nabla(\rho\bar{u}\bar{u})=\rho\beta(T-T_{heater})\alpha \qquad (3)$$

$$\rho c_p\bar{u}\nabla T=k\nabla^2 T \qquad (4)$$

In the above equations, $\bar{u}$ is the velocity vector, t is the time, and ∇ is nabla. ρ, p, and α are density, pressure, and acceleration, respectively, and C_p, T, and k are the fluid specific heat, temperature, and thermal conductivity, respectively. In addition, with the ideal gas constant R one has the relationship of states ρ and p as:

$$\rho=\frac{p}{RT} \qquad (5)$$

By using hemi-spherical chamber and filled with Xe gas, the thermal sensors temperature differences vs. angular accelerations for the thermal sensors at points 1, 2 and 3 are as in Fig.11. Note the sensitivity is far better (258°C/(rad/s^2) to put the thermal sensors at point 2 and the linearity is also good. So we put thermal sensors at this place for the following analysis of the step-input angular acceleration responses of Xe gas velocity, static pressure and total enthalpy, the results are as in Figs.12 and 13. The detailed response times of step-input angular accelerations for static pressure and total enthalpy are also listed in Table I, respectively. Note the response time of step-input angular acceleration for the hemi-spherical chamber filled with Xe gas is 81μs.

Table I. The step-input response times

Static Pressure	Total Enthalpy	Gas Velocity
81μs	52μs	74μs

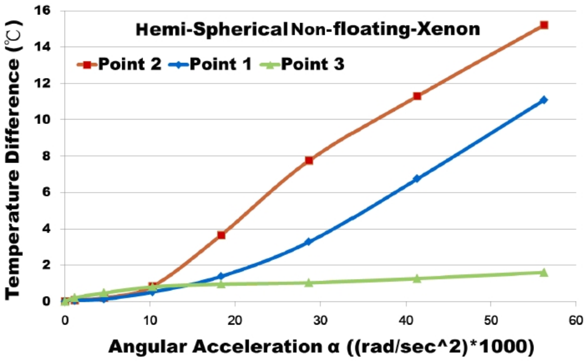

Figure 11 The thermal sensors temperature differences vs. angular accelerations by using hemi-spherical chamber filled with Xe gas for the thermal sensors at points 1, 2 and 3.

4. Conclusion

The contributions of this paper are summarized as follows:

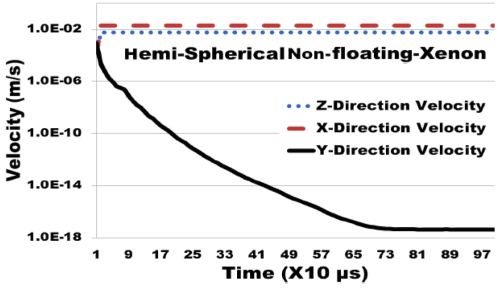

Figure 12 The step input angular acceleration responses of gas velocity.

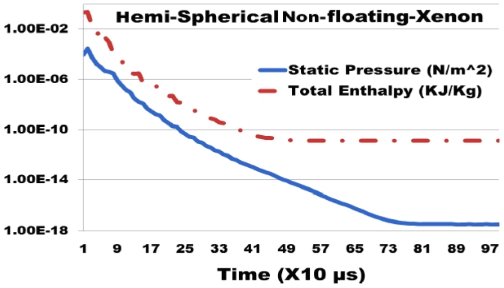

Figure 13 The step input angular acceleration responses of static pressure and total enthalpy.

(1) The first innovative idea of the proposed device is to make it directly on a flexible substrate without any movable parts and grooved cavity, so it is very easy to make and reliable.

(2) This is a brand new idea to make both heater and temperature sensors on a flexible substrate by using lower temperature process, such as evaporation, which is not proposed before.

(3) Thus one can integrate the RFID tag with the thermal convection angular accelerometer on the plastic substrate to make a more powerful wireless angular acceleration sensor.

(4) This is a new idea to use flexible substrate, its thermal isolation capability is better than the traditional silicon, thus the cost of power dissipation for long time operation is lower for the new design. Besides, the inert Xe gas is more reliable without oxidation and aging effects.

(5) The sensitivity and the response time of the new thermal convection angular accelerometer are 258°C /(rad/s^2) and 81μs, respectively.

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