Flat Film Structure Wireless Passive Pressure Sensor based on SiCN materials

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Abstract. In order to solve the measurement of air pressure in harsh environment, a new kind of wireless passive pressure sensor based on the amorphous SiCN material with high heat resistance was proposed. Ansoft HFSS software was used to study the relationship between the size of the rectangular resonator with the resonant frequency and quality factors. By optimizing the position and size of the sloped antenna, a wireless passive pressure sensor with high performance was designed. The sensitivity is 0.25mpa /GHZ and the bandwidth is 0.85GHZ of the pressure sensor at the working frequency of 6.8GHZ. This indicates its potential application in the harsh environment with high temperature.

1. Introduction

With the development of microelectronic technology, the micromechanical pressure sensor has been widely used in many areas, such as it has great application prospects in the field of civil aviation. However, due to the limitations of current materials, current silicon-based pressure sensors can only work in some mild environments [1]. Ordinary silicon-based materials can only work normally at temperatures up to 350°C. At present, micromechanical pressure sensors are still lacking in the application field of high temperature environment [2].

Subsequently, many heat-resisting materials have been used to make pressure sensors to replace silicon, such as polycrystalline diamond, silicon carbide and ceramics. These materials have very high heat resistance. Polycrystalline diamond pressure sensor uses diamond film and varistor to measure the pressure change [3]. Silicon carbide pressure sensor is also measured by using silicon carbide film and varistor. All of these technologies can be used to make high temperature pressure sensors. However, the manufacturing technologies of these materials are not as mature as the silicon-based pressure sensors.

Since the middle and late 20th century, the precursor volumetric transformation ceramics (PDC) method has gradually come into people's vision. The precursor conversion ceramics is obtained with a method of chemical synthesis. Through heat treatment and a series of simple processes, the polymer...
is converted into ceramic materials. The polymer has good machinability due to the fact that it can be a solution or a liquid. Furthermore, compared with other ceramic preparation methods, the temperature of the PDC method is usually low. This effectively reduces the cost [4].

In order to improve the stability of the micro-mechanical sensor in harsh environment and ensure the normal operation of the sensor, this paper selected PDC SiCN to make high temperature pressure sensor in combination with the current technical level. The sensor uses the wireless sensor technology to measure the pressure change. The pressure is converted into frequency shift output, and the frequency shift signal can be detected at a distance [5]. Due to the sensor USES wireless sensing technology, there is no need to directly supply energy to the sensor. So this technology is very suitable for pressure measurement under high temperature environment. Ansoft HFSS software was used to analyze the rectangular resonator based on SiCN medium, and the structure size of the rectangular resonator was studied when the intrinsic quality factor \( (Q_0) \) and the intrinsic resonance frequency \( (f_0) \) reached the appropriate level. Then the structure size of slotted antenna is studied when the radiation quality factor \( (Q_r) \) and resonant frequency \( (f_r) \) reach the appropriate level. Through a series of analysis and optimization, the wireless passive pressure sensor model of the flat mode structure is finally determined [6].

2. Design Of Pressure Sensor

The flat film wireless passive pressure sensor was composed of rectangular amorphous SiCN ceramic block, and its inner surface had a high heat resistant metal layer. The upper surface of the sensor was a rectangular amorphous SiCN ceramic pressure film [7]. Its inner surface was equipped with a high heat resistant metal layer and a coupling antenna that transmitted signals to the outside world. The SiCN pressure film coated with metal layer was bonded with the SiCN body material by the precursor polysilazane to form a pressure chamber, and finally the wireless passive pressure sensor was formed. The structure diagram of the sensor is shown below. The deformation quantity of the pressure film under pressure was linearly related to the frequency of the resonator [8]. Therefore, by measuring the variation of resonance frequency, we can measure the distribution data of external pressure field.

![Transverse profile structure of pressure sensor.](image)

Before the slotted antenna was set, the solution mode of eigen-mode was selected. By optimizing the size of the model, the optimal value was selected to calculate the intrinsic quality factor \( (Q_0) \) and resonance frequency \( (f_0) \) of the model. After the slotted antenna was set, the solution was obtained by simulation results.

\[
Q_t = \frac{f_0}{\Delta f_{-3dB}} \frac{1}{1 - \text{mag}(S_{21})} 
\]

(1)

The relationship between intrinsic quality factor \( Q_0 \) and radiant quality factor \( Q_r \) can be expressed as:
When the intrinsic quality factor ($Q_0$) was approximately equal to the radiant quality factor ($Q_r$), the resonator reached the maximum signal output [9],

\[ Q_r = Q_0 \]  

(3)

In the eigen-mode, the focus of this paper was to obtain intrinsic resonance frequency $f_0$ and intrinsic quality factor $Q_0$ by optimizing and selecting the resonator size. In the driving mode, the radiant quality factor ($Q_r$) was calculated by optimizing the size of coaxial probe and the slotted antenna. In order to find the most suitable parameter size, the relationship between model size and radiation quality factors were explored. When $Q_r=Q_0$, the slotted antenna and the resonator reached the maximum electromagnetic energy coupling. At this point, the coupling coefficient of the resonator was approximately 1, and the maximum signal output was achieved [10].

3. Simulated Analysis

3.1. Analysis of rectangular amorphous SiCN pressure film

By analyzing the film thickness of different sizes, the linear relationship between the thickness and intensity of pressure was obtained. The relationship between intensity of pressure and thickness was analyzed when the length-width ratio is 1:1, length-width ratio is 2:1, and length-width ratio is 3:1 respectively. In this paper, a film with length-width ratio of 2:1, a film with a length of 15mm and a width of 7.5m, was adopted. By changing the film thickness from 0.3mm to 1mm, the flat film deformation between 0 and 8MPa was observed.

It can be seen from Figure 2 and Figure 3 that when the film thickness is 0.3mm, the relationship between intensity of pressure and deformation quantity is nonlinear, and the other film thicknesses can keep the linear trend.

![Figure 2](image_url)  
Figure 2. The length-width ratio of flat film is 2:1.

![Figure 3](image_url)  
Figure 3. Relationship between pressure and deformation at different film thickness.
3.2. The solution of the eigen-mode

The model of resonator was established. The dielectric material SiCN was taken as the dielectric fillers. The relative permittivity of SiCN is 3.6, and the tangent of loss Angle is 0.005. The metal layer on the inner surface of the resonator is silver, and its thickness $t=0.03\text{mm}$, as shown in the figure below.

3.2.1. The length of the medium SiCN was changed

The length of SiCN was set as $15+x_1$, and the default value of $x_1$ is 3mm. The range of scan parameters was set as $(1\sim5\text{mm})$. The step value was set as 1mm. After the simulation is completed, the simulation data was checked, the intrinsic quality factor ($Q_0$) and the intrinsic resonance frequency ($f_0$) was derived, and finally the data was analyzed to get the relationship as shown in the figure below [11].

It can be seen from Figure 5 that intrinsic resonance frequency and intrinsic quality factors were decreased with the increase of medium length.

![Figure 4. The structure of the eigen-mode.](image)

![Figure 5. Relationship between SiCN length and $Q(0)$ and Frequency.](image)

3.2.2. The size of resonator was determined

Other dimensional parameters can be obtained from the same principle. The intrinsic quality factor was related to the precision and sensitivity of the sensor. The increase of intrinsic quality factors resulted in the increase of wireless sensor distance. Therefore, when selecting the intrinsic quality factor ($Q_0$) of the resonator model in the eigen-mode, the intrinsic quality factor should take a larger value. The size of the medium was determined, where the length is $x_1$, the width is $y_1$ and the height is $z_1$, their values are 1mm, 1mm and 4mm respectively. The size of the inner cavity was determined with the length 15mm, the width 7.5mm and the height 3mm. $Q_0=1103.06$, $f_0=8.66\text{GHz}$, where $Q_0$ is the intrinsic quality factor and $f_0$ is the corresponding intrinsic resonant frequency.
3.3. Determination of coaxial probe and antenna dimensions

On the basis of determining the size of the resonator model, a coaxial probe was added on the lower surface of the resonator, and a slotted antenna was added on the metal layer of the inner surface of the film, as shown in the figure.

On the lower surface are two coaxial probes, which were made of copper. The outer surface of the probe is Polytetra-fluoroethylene, which has a radius three times that of the probe. The distance between the coaxial probe and the lower surface of the center is set to \(a\). The length and width of the slotted antenna on the upper surface are set as \(x_2\) and \(y_2\) respectively, \(bb\) was slotted antenna's distance to the center of the upper surface.

![Figure 6. Model of the front view.](image)

The control variable method was used to explore the position and size of the coaxial probe, as well as the influence of the position and size of the slotted antenna on the resonant frequency of the resonator. The initial value of the inner ring of the coaxial probe was set as 0.1mm. The distance between the center of the circle and the center of the lower surface was set as 3mm. The initial length and width of the slotted antenna were set as 4mm and 0.5mm respectively, it is 3mm away from the center of the upper surface.

3.3.1. Simulation of coaxial probe position.

The length and width of slotted antenna were set as \(x_2\) and \(y_2\) with value of 5mm and 0.5mm respectively. The distance from the slotted antenna to the center is 1.5mm. The range of scan parameters was set as (1~7mm). The step value was set as 1mm. After the simulation is completed, the simulation data was checked. The relationship between Frequency and S21(dB) were obtained, and finally the data was analyzed to get the figure relationship [12].

![Figure 7. Relationship between the distance of coaxial probe to the center of the lower surface and resonant frequency (fr) and S21(dB).](image)

When the location of the coaxial probe was properly selected, there was a maximum value in the figure with a large range of variation nearby. As shown in the figure, when the distance between the coaxial probe and the center of the lower surface is 5mm, the position is reasonable.
3.3.2. **Determination of position and size of coaxial probe**

The same procedure may be easily adapted to obtain the size of models for any other parameters. To sum up, when the distance between the coaxial probe and the center of the lower surface is 5mm, the radius of the inner ring is 0.1mm, and the length h is 8mm, the size is relatively reasonable.

3.4. **Simulation of slotted antenna**

3.4.1. **Position analysis of slotted antenna.**

The length and width of slotted antenna were set as x₂ and y₂ with value of 4mm and 0.5mm respectively. The approximate coupling state is achieved by changing the position. The range of scan parameters was set as (1~5mm). The step value was set as 1mm. The simulation is completed. The radiation quality factor was obtained by resonance frequency (\(f_r\)), the bandwidth of -3dB is \(\Delta f_{-3dB}\) and mag (S21). The relationship between the distance from the slotted antenna to the center of the upper surface and the radiation quality factor, as well as the relationship between the distance and resonance frequency are obtained, as shown in the figure.

![Figure 8](image)

Figure 8. The distance from the slotted antenna to the center of the upper surface is related to \(Q(r)\) and \(F(r)\).

Figure 8 shows that when the distance between the slotted antenna and the middle center of the upper surface was 1.5mm, the selection is reasonable.

3.4.2. **Determination of the position and size of slotted antenna.**

Likewise may result in other size. In summary, when the distance between the slotted antenna and the center of the upper surface was set as \(b_b\), the length of slotted antenna was set as x₂ and its width was set as y₂, their values was 1.5mm, 5mm and 0.5mm respectively, the radiation quality factor of the sensor is approximately equal to the intrinsic quality factor. The coupling coefficient is approximately 1. At this time, the maximum output signal is obtained, so the distance between the slotted antenna and the center of the upper surface was finally determined as \(b_b = 1.5mm\). The slotted antenna length \(x_2 = 5mm\), width \(y_2 = 0.5mm\).

4. **Conclusion**

A new kind of wireless passive pressure sensor based on the amorphous SiCN material was proposed. Due to the introduction of SiCN materials, it has great potential application in the harsh environment with high temperature. By optimizing the position and size of the sloped antenna, a wireless passive pressure sensor with high performance was designed. The sensitivity is 0.25MPa /GHZ and the bandwidth is 0.85GHZ of the pressure sensor at the working frequency of 6.8GHZ.

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