Structure Optimized of Uncooled Infrared Sensors

Yuan-qing WU, Yang WANG, Chun-mei Liu, Yu-feng ZHANG, Xiao-dong LU and Tao ZHOU

College of New Energy, Bohai University, Jinhao, 121013, China

Keywords: Uncooled, Infrared thermal response, FEM simulation, MEMS.

Abstract. The resistive bolometer based on VOx was studied in the paper. Modeling and simulation was done, and structure was optimized by comparing the different results in thermal and mechanical simulation with different structure and material properties. The improved structures have better thermal response capacity and the mechanical performance, and the absorption efficiency of heat flow has increased by about 18.1%, laid the foundation for the structure amelioration of the uncooled thermal detector.

Introduction

In recent years, the technology of infrared imaging systems has developed rapidly, whose performance is often limited by infrared detectors. Infrared sensors are classified into two types, cooled and uncooled. The costly and bulky fatal flaws of the refrigerated infrared detectors make them only suitable for military applications and cannot be used in civilian applications. Uncooled infrared sensors do not require expensive refrigeration equipment and can operate at room temperature, greatly improving their application prospects. With the rapid development of technology, the performance of uncooled heat detectors has greatly increased, and there has been a gradual replacement of refrigeration-type detectors.

Infrared bolometer is a type of uncooled infrared detector whose principle is to detect the infrared radiation intensity based on the electrical effects of sensitive materials after infrared radiation. The temperature of the sensor changed by absorbing infrared radiation, and the external infrared radiation can be measured.

Compared to other types of uncooled infrared sensors, bolometers use a thermistor material to read the infrared signal changes with temperature. No auxiliary readout circuit such as a demodulator is required and easy to prepare. The process is fully compatible with standard semiconductor processes and is easily integrated with integrated circuits. The self-sustained cantilever beam has good thermal insulation and high image clarity, has received extensive attention from researchers.

This paper studies the design of an infrared uncooled thermal imaging sensor based on VOx sensitive thin film, through structural optimization and parameter adjustment to get a better infrared bolometer model.

Device Model and Principle

The structure used in this paper is a double cantilever support structure, Figure 1 is a structural sectional view of the heat detector, who have four layers: passivation layer, absorption layer, support layer, and reflective layer.

The upper and lower surfaces of the device are respectively two layers of silicon nitride, the upper layer of silicon nitride is a passivation layer, the lower layer is a support layer, with Vanadium oxide is used as a sensitive material. When infrared light is irradiated on the detector, part of it is absorbed by the absorbing layer, and another part passes through the absorbing layer and the sensitive film is reflected back by the supporting layer and is absorbed by the absorbing film again. In order to obtain good thermal insulation performance, a cantilever structure is used as a thermal insulation layer. The use of aluminum, which has a relatively good conductivity, serves as
an electrode to conduct electricity, and nickel cadmium, which has a low thermal conductivity and a low specific resistance, is used as a lead to transfer an electrical signal to a processing circuit.

![Diagram](image)

Figure 1. Profile of uncooled infrared sensor.

The device is 25μm * 25μm size, double cantilever support structure, material properties is shown in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus (GPa)</th>
<th>Poisson's ratio</th>
<th>Density (g/cm³)</th>
<th>Coefficient of thermal expansion (10⁻⁶/°K)</th>
<th>Resistivity (Ω·m)</th>
<th>Thermal Conductivity (W/m·°K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiN₅</td>
<td>300</td>
<td>0.270</td>
<td>2.55</td>
<td>16</td>
<td>10.46</td>
<td>35</td>
</tr>
<tr>
<td>NiCr</td>
<td>200</td>
<td>0.312</td>
<td>8.90</td>
<td>133</td>
<td>1.67×10⁻⁸</td>
<td>90</td>
</tr>
<tr>
<td>Al</td>
<td>74</td>
<td>0.350</td>
<td>2.70</td>
<td>231</td>
<td>2.66×10⁻⁸</td>
<td>235</td>
</tr>
<tr>
<td>SiO₂</td>
<td>70</td>
<td>0.170</td>
<td>1.98</td>
<td>5</td>
<td>10.21</td>
<td>1</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>50</td>
<td>0.360</td>
<td>4.34</td>
<td>5</td>
<td>0.10</td>
<td>22</td>
</tr>
</tbody>
</table>

Simulation

For infrared bolometers, the heat flow balance equation for heat absorption is:

\[
C \frac{d(ΔT)}{dt} + G(ΔT) = \eta P = \eta P_0 \exp(jσt)
\]

In, T is time. C is the heat capacity of the detector, G is the thermal conductivity of the detector, σ is the modulation angular frequency of the thermal radiation, the optical power amplitude is P₀ and the incident light absorption efficiency, and the pixel temperature rises above the sensitive area is ΔT.

Solving (1), then:

\[
ΔT = \frac{\eta P_0 \exp(jσt)}{G + jσC} = \frac{\eta P_0}{G(1 + σ^2τ^2)^{−1/2}}
\]

(2) is the basis of infrared heat detection arrays. It describes the increase or decrease in temperature when the incident power P₀ is incident on the detection pixel.

Results and Discussion

A heat flow of 3200 W/m² was applied to the upper surface of the silicon nitride passivation layer to simulate the temperature rise of the device caused by infrared radiation. Fig. 2 shows the thermal simulation results of the device. The temperature of the device rises and the body temperature rises to 25.7755 degrees Celsius. It is known that the device has a thermal response capability, and it is initially confirmed that the device can meet the requirements of a general infrared heat detector, but the performance needs to be improved.
Cantilever Optimization

The cantilever structure bears the function of thermal isolation, electrical conduction and structural support. The heat loss of the device mainly comes from the heat conduction, so its performance determines the working effect of this device, then the cantilever beam size was adjusted.

The cantilever scale was changed from 3 microns to 1 micron, then we have structure B, which can reduce heat loss, improve the performance of the device, and increase the effective heat-absorbing area of the sensor.

Simulation result of is structure B shown in Fig.3. Under the same heat flow, both of these two sensors have corresponding temperature increase, a relatively uniform distribution, a good thermal response capability, the maximum temperature is located on the main bin, and the temperature on the cantilever decreases with increasing length to Room temperature.

The maximum temperature rise of structure A is 25.7755°C, while the maximum temperature rise of structure B is 28.4005°C. Under the same heat flow, structure B has a narrow cantilever, a smaller thermal conductivity, and less heat loss through the cantilevers, and more focused on the main unit area of the probe unit, so the temperature rise of the structure B is relatively large (maximum of about 28.4005 °C), visible structure B has better thermal response than structure A, more sensitive to temperature.

Passivation Layer Thickness Optimization

The thermal sensor mainly reflects the device's ability to absorb and react to heat. From the point of view of the sensor structure, the silicon readout circuit is usually supported on the top of the silicon readout circuit by a thermally insulated microbridge made of silicon nitride with a small thermal conductivity, and the vanadium oxide film is deposited on the bridge surface. Heat-sensitive films, which are connected to the signal processing circuitry in the Si substrate via the leads on the two support arms. Most of the heat absorbed by the sensitive film can only be transferred from the support arm to the Si substrate, which reduces the thermal conductivity of the detector and increases the temperature variation caused by infrared radiation. Above the resistor, Si3N4 is used as the infrared absorption film. When the infrared light is irradiated on the detector, part of the absorption
layer is absorbed by the absorption layer, and the other part is reflected back through the absorption layer and the sensitive film, and is absorbed by the absorption film again.

From the above it can be seen that the thickness of the passivation layer of silicon nitride has a significant effect on the device performance. First of all, the heat radiation must be passed through it to the position of the absorber layer, but also to protect and insulate the device. Different thicknesses of passivation layer have different effects on the heat absorption efficiency. Based on this, we simulate the devices with different thicknesses of passivation layers.

Fig.4 below shows simulation results of temperature changes for the same heat flow (3200w/m²) for 0.2μm, 0.1μm, 0.05μm, 0.02μm thickness, assuming an ambient temperature of 25°C.

It can be clearly seen that the thermal simulation results are completely different for different thickness models. Although the general shape of the temperature distribution is indistinguishable, the main heat absorption effect is completely different. The thinner the thickness of the passivation layer is, the better the heat absorption effect will be, and the trend will decrease in an exponential manner. However, considering the actual process and the application environment of the device, the thickness should not be too thin, otherwise it will not protect the device. As a result, it is recommended that the passivation layer thickness be between 0.1μm and 0.05μm.

![Figure 4. The relationship between the thickness of passivation layer and temperature rise.](image)

**Optimized Model**

The width of the cantilever has a great influence on the performance of the device, heat loss is likely to occur. With the same area of the device, an increase in the cantilever area means a decrease in the heat absorption area. However, with a relatively wide cantilever structure, the narrow cantilever has obvious deficiencies in the stability of the device, which is not conducive to the stability of the device.

In order to save the space of the device and reduce the waste of the area, the original electrode position is adjusted, and the original slightly inclined structure is adjusted to a purely rectangular structure, so that the heat absorption area of the device can be improved. The increase contributes, and because the electrodes of the device are placed on the circuit, the position is corresponding. Therefore, the right-angle structure facilitates the arrangement and placement of the processing circuits, increases the efficiency of use of the device, and also reduces the amount of work required when manufacturing the reticle.
Figure 5. Simulation result of new structure.

Figure 5 shows the simulation results. It can be seen that the temperature increase of the device is obvious. Under the same heat flow, compared with the original structure, the cantilever of this structure is narrower, the heat loss area is greatly reduced, and at the same time, the heat absorption area is increased. So the heat absorption effect is better. Compared with the simulation result of structure A, the maximum temperature rise of this structure reaches 0.9162, and the maximum temperature rise of the original structure is 0.7755. Since the size of the two devices is equivalent, the ratio of maximum temperature rise is close to the ratio of heat absorption efficiency. It can be seen that the heat absorption efficiency has increased by about 18.1%.

Conclusion

This paper uses IntelliSuite to model and simulate the structure of the microbolometer probe unit. First, through the simulation of the basic probe unit structure, the influence of the structure of the probe unit on its performance is studied. Then by analyzing the simulation results, the structure of the detection unit is modified, and the improved structure is proposed and modeled and simulated. The dissertation focuses on the thermal simulation of the detection unit. The improved structure has better thermal response and mechanical performance, which provides a certain research basis for optimizing the structure of uncooled thermal imaging detectors.

Acknowledgment

This paper is supported by National Natural Science Foundation of China (NSFC), No. 61575029; The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R. B. G.) thanks” Instead, try “R. B. G. thanks”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

References


