Miniature pyranometer with asteroid shape thermopile

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Abstract— **We have designed and fabricated a miniature pyranometer with a novel asteroid shape thermopile. Comparing with existing pyranometer, the size of our miniature pyranometer has been reduced to 8mm×4mm×0.5mm, and much metal material has been saved in our pyranometer. Test results of this pyranometer show: (a). the output of this pyranometer is proportional to input illuminance. (b). the resolution of this pyranometer with a pre-amplifier is 0.191mV/10^{5}Lux. (c). As the maximum illuminance of sunshine is about 100,000Lux, the sensitivity of this fabricated pyranometer is receptible. The further test and improvement such as the reliability test of the sensor and the optimum design of material and structure of the sensor will be performed in the next work in the future.**

***Keyword*—miniature pyranometer, asteroid shape thermopile, solar radiation**

I. INTRODUCTION

Measurements of solar radiation are essential to both atmospheric science and renewable energy system design and research. Pyranometer is the instrument that measures the solar radiation flux density [1]. So far, almost all the pyranometers are thermopile type formed by a number of twisted metal wires. Such thermopile normally has hot and cold junctions with equal number. Hot junction is also called measuring junction, and cold junction is also called reference junction. The temperature difference between the measuring and reference junctions produces a voltage that is proportional to the solar radiation. Recently, since the renewable energy system technology and wireless sense network technology have been developed rapidly, a large quantity of pyranometer with small size was highly needed. Depending on microelectromechanical systems (MEMS) technology, the size of a device can be reduced much more, and a number of the material such as the metal of thermopile can be saved. Based on MEMS technology, we have fabricated a miniature pyranometer with novel designs on thermopile and the structure of device. The resent test result of the fabricated miniature pyranometer show the output of the sensor is proportional to input illuminance, and the sensitivity of this fabricated pyranometer is receptible. The further test and improvement such as the reliability test of the sensor and the optimum design of material and structure of the sensor will be performed in the next work in the future.

II. DESIGN OF DEVICE

The core principle of our miniature pyranometer is the mechanism of thermopile. Normally, in order to ensure a thermopile has a continuous output, hot spot and cold spot are necessary. The hot junction of thermopile should be located at the hot spot, and the cold junction of thermopile should be located at the cold spot. The stable difference of the temperature between hot spot and cold spot ensure the continuity of the output of the thermopile. Fig.1 presents a schematic illustration of our design of the micro-electro-mechanical system (MEMS) based miniature pyranometer. As shown in Fig.1, this device has three parts mainly: substrate, silicon membrane and thermopile layer.

A. The two functions of silicon membrane

In this device, both the substrate and 20μm thickness silicon membrane are silicon. The silicon membrane of this device has two functions. One is the support of the thermopile unit, the other one is the thermal insulative structure. There are two factors to ensure that the heat loss through silicon membrane is little. The first factor is the relative lower thermal conductivity of 20μm thickness silicon membrane compared with bulk silicon material. In solid state physics, to a certain kind of material, the thin film has a relative low thermal conductivity than bulk material [2]. The second factor is the very little contact area between the silicon membrane and substrate, due to the fact that the thickness of silicon membrane is very thin.

approximately equal. The whole thermopile of our pyranometer forms an asteroid shape shown in Fig.2.

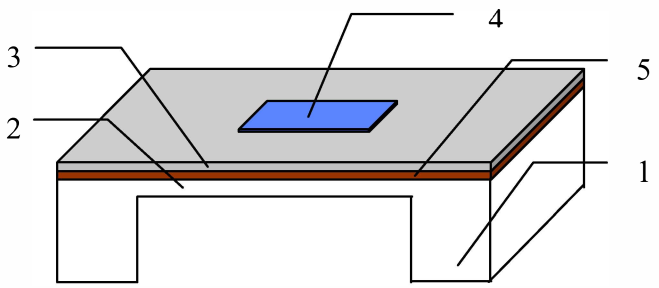

Fig.1. Schematic of miniature pyranometer:
1. silicon substrate; 2. silicon membrane;
3. thermopile layer; 4. radiation absorption layer;
5. electric insulative layer.

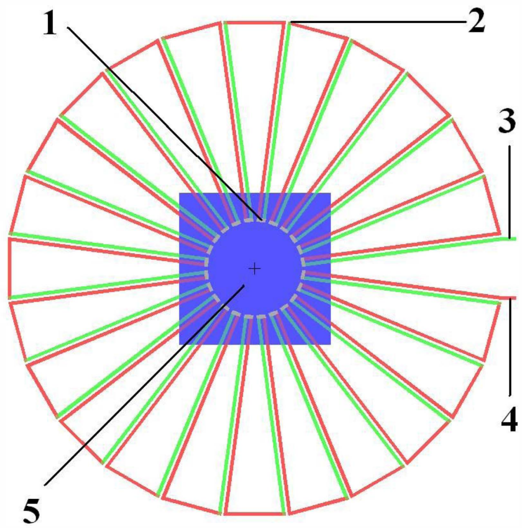

Fig.2. Schematic of thermopile layer :
1. hot junction; 2. cold junction; 3. NiCr electrode;
4. Ni electrode; 5. radiation absorption layer

B. The radiation absorption layer and the hot spot

As shown in Fig.1, the radiation absorption layer was located at the central area of the silicon membrane. Because the film of Si_3N_4 is superior radiation absorption material [3], we chose Si_3N_4 film fabricated by plasma-enhanced chemical vapor deposition (PECVD) technology as the radiation absorption layer with thickness of 0.5 μ m. Due to the thermal insulative function of the silicon membrane, most of the heat absorbed by the radiation absorption layer was insulated by the silicon membrane. Since the substrate is the bulk material of Si, we can regard the substrate of the device as a heat sink. Therefore, when the solar radiation irradiates the device continually, there is a continuous difference of temperature between the radiation absorption layer and the substrate of device. This difference of temperature depends on the solar radiation flux density. So, we chose the central area of silicon membrane as the hot spot of the thermopile of our pyranometer, and chose the substrate of the device as the cold spot of the thermopile of our pyranometer. Thus, the output of thermopile is proportional to the solar radiation flux density.

C. Asteroid shape thermopile

We chose Ni and NiCr to make the junctions of the thermopile in our pyranometer. As shown in Fig.2, the hot junction of this thermopile beneath the radiation absorption layer, is located at the central area of the silicon membrane. The cold junction of this thermopile above the electric insulative layer, is located at the edge of thermopile layer. Because the electric insulative layer (Si_3N_4 film with thickness of 0.2 μ m) is very thin comparing with the silicon substrate (thickness of 350 μ m), the temperature of the edge of thermopile layer and the silicon substrate of the device are

III. FABRICATION OF DEVICE

There are two steps in the fabrication of this miniature pyranometer mainly. Figure.3 showed the Schematic diagram of the fabrication process of this device.

As shown in Fig.3 (a), the first step is the formation of the thermopile layer and radiation absorption layer. The thermopile unit is formed by sputtering technology. Then the radiation absorption layer (Si_3N_4 film) is deposited above the thermopile layer by plasma-enhanced chemical vapor deposition (PECVD) technology.

As shown in Fig.3 (b), the second step is the formation of the silicon membrane. Deep reactive ion etching (DRIE) was used in another side of the wafer to form this silicon membrane.

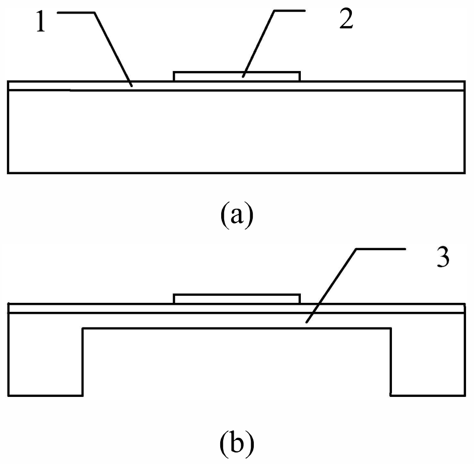

Fig.3. The fabrication process of miniature pyranometer:
(a): the formation of the thermopile layer and radiation absorption layer: 1.thermopile layer, 2. radiation absorption layer;
(b): the formation of silicon membrane: 3.silicon membrane

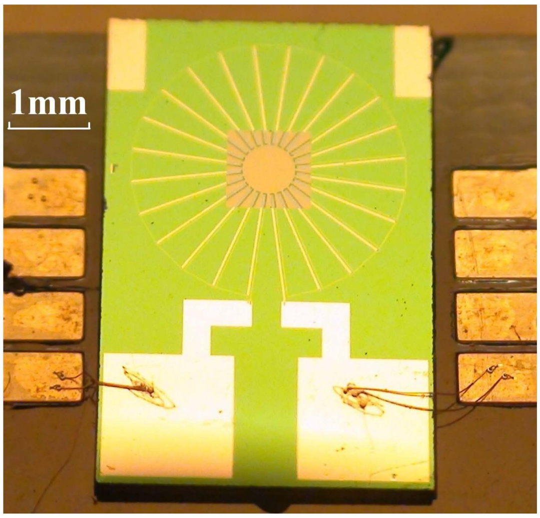

Fig.4. The photography of fabricated miniature pyranometer

IV. TEST AND RESULT

Fig.4. shows a fabricated miniature pyranometer. The size of this device is 8mm×4mm×0.5mm. The width of the beam of the thermopile in this fabricated pyranometer is 30 μm. The thickness of the radiation absorption layer of this pyranometer is 0.5 μm. The thickness of the silicon membrane is 20 μm. A pre-amplifier is used to amplify the output of this fabricated pyranometer. Fig.5. shows the performance of this fabricated pyranometer. The test results show: (a). the output of this pyranometer is proportional to input illuminance. (b). the resolution of this pyranometer with a pre-amplifier is 0.191mV/10^5Lux. (c). As the maximum illuminance of sunshine is about 100,000Lux, the sensitivity of this fabricated pyranometer is receptible. The further test and improvement such as the reliability test of the sensor and the optimum design of material and structure of the sensor will perform in the next work in the future.

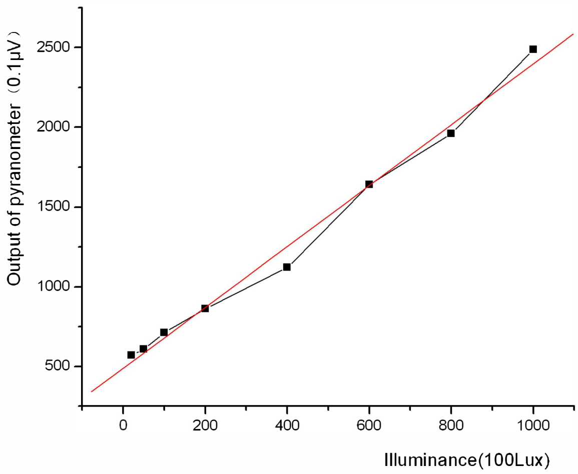

Fig.5. Test result of fabricated miniature pyranometer

V. Conclusion

We have designed and fabricated a miniature pyranometer with a novel asteroid shape thermopile. Comparing with existing pyranometer, the size of our miniature pyranometer has been reduced to 8mm×4mm×0.5mm, and much metal material has been saved in our pyranometer. Test results of this pyranometer show: (a). the output of this pyranometer is proportional to input illuminance. (b). the resolution of this pyranometer with a pre-amplifier is 0.191mV/10^5Lux. (c). As the maximum illuminance of sunshine is about 100,000Lux, the sensitivity of this fabricated pyranometer is receptible. The further test and improvement such as the reliability test of the sensor and the optimum design of material and structure of the sensor will be performed in the next work in the future.

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