A Novel Micromachined Microwave Power Sensor Using GaAs MMIC Process

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Abstract. The theory, design, and fabrication of a novel structure for measuring power of microwave signals are presented. The novelty of this sensor is that it measures the microwave power with which is coupled from the CPW line by the MEMS membrane. In this method the signal is available during the power detection. The simulation and process of this sensor are given.

1. Introduction

Power detection is an important part of microwave and millimeter wave wireless applications and measurement technology. The existing technology for measuring microwave and millimeter wave power is based on thermistors, thermocouples and diodes. These are terminating device, and the signal can’t be used after power detection. Recently, two new sensing principles of inline type MEMS microwave power sensor are proposed. The first principle utilizes the conversion of electrical power into heat resulting in a local temperature increase due to the ohmic losses of the center conductor of a CPW line [1-3]. The second principle is based on capacitive MEMS technology, and the power measurement is realized by the movement detection of a suspended membrane over a CPW line where the signal is transmitted [4-7]. These sensors can be used in the middle of the signal chain with small losses, and the signal can still be used after power detection. They can be used in portable device or base station.

In this paper, the theory, design, and fabrication of a novel structure microwave power sensor are presented based on MEMS technology. The microwave power detection is realized by the measurement of the microwave power with which is coupled by the MEMS membrane. This sensor has low reflection of less than -20dB and low insertion loss of less than 0.2dB in the X-band frequency range. The sensitivity of this power sensor is more than 10mV/W.

2. Operation principle

The operation of the sensor is based on the capacitance between the MEMS membrane and the center conductor of the CPW line. The capacitance C can be expressed as [8]

$$ C = \frac{\varepsilon_0 h W}{g_0 + \frac{I_d}{\varepsilon_r}} $$

(1)
where $b$ is the width of the MEMS membrane, $w$ is the width of the center conductor of the CPW line, $g_0$ is the membrane height, $t_d$ is the thickness of the insulation layer, $\varepsilon_0$ and $\varepsilon_r$ are the permittivity of free space and the permittivity of the insulation layer, respectively.

The capacitance couples a small ratio of the microwave power which is transmitted in the CPW line. The $S$ parameter of the novel microwave power sensor can be expressed as

$$S_{11} = -\frac{Z_0}{2Z_0 + 2R_s + j2\left(\omega L - \frac{1}{\omega C}\right)}$$

$$S_{21} = -\frac{Z_0}{2Z_0 + 2R_s + j2\left(\omega L - \frac{1}{\omega C}\right)}$$

where $C$ is the capacitance between the MEMS membrane and the center conductor of the CPW line, $R_s$ is the resistance of the MEMS membrane, $L$ is the inductance of the MEMS membrane and $Z_0$ is the characteristic impedance of the CPW line. Then, the coupled microwave power is converted to heat by a matched resistance, and the thermopile detects the resultant temperature increase of the load and converts the temperature difference to electric signal to realize microwave power measurement. This sensor can realize the measurement of average power, and has many advantages as independent of signal waveforms, high dynamic range, small size, low weight and power consumption. The possible applications of such a microwave power sensor include portable devices, base stations or military purposes.

Fig.1 shows a schematic drawing of the basic sensor structure. The sensor is composed of the microwave power coupler and the indirectly-heated type microwave power sensor. Fig.2 shows the structure of the microwave power coupler. It is similar to the capacitive MEMS switch: the MEMS membrane is suspended over the CPW line, but the anchor of the MEMS membrane isn’t connected with the ground of the CPW line. In the end of the CPW line connected to the anchor is the matched resistance. Fig.3 shows the structure of the indirectly-heated type microwave power sensor. The thermopile is near the matched resistance.

![Figure 1. Schematic view of the novel microwave power sensor design](image-url)
3. Design and fabrication

The microwave signal is transmitted by the CPW line. At a certain position, the gold MEMS membrane is suspended over the CPW line. The width of the MEMS membrane is designed with 70μm and 80μm. With different width of the membrane, the tradeoff between microwave properties and sensitivity can be obtained. The S parameters of the microwave power coupler were simulated with HFSS. Figure 4 shows the S parameters of the microwave power coupler design with 70μm and 80μm of the width of the membrane. From the S parameters, it shows that the reflection of the sensor is to achieve S11 less than -20dB and the insertion losses is to achieve S21 better than -0.2dB in the X-band frequency range. The coupled microwave power is dissipated by the matched resistance. The distance between the matched resistance and the thermopile is designed with 10μm and 20μm. Two different distances are designed in order to obtain the relation between the sensitivity and the distance. The temperature distribution of the indirectly-heated type microwave power sensor was simulated with CoventorWare. Figure 5 shows the temperature distribution of the indirectly-heated type microwave power sensor design with 10μm and 20μm of the distance between the matched resistance and the thermopile with the input power of 10mW at room temperature of 300K. With a Seebeck coefficient of 100μV/K, it shows that the sensitivity of this power sensor is more than 10mV/W.
The fabrication of this novel power sensor can be fully compatible with the GaAs MMIC process. The CPW line was designed to have $50\,\Omega$ characteristic impedance. The CPW and the membrane were made by electroplating of a 2μm thick gold layer and the gap between the membrane and the center conductor of the CPW line was determined by 1.6μm of polyimide. The thermopiles were made of gold and n⁺ GaAs with a Seebeck coefficient of 100μV/K. The gold was made by sputtering of a 0.3μm thick gold layer, and the n⁺ GaAs was made of a 0.25μm thick epitaxial layer. The matched resistance was made by depositing of a TaN layer with square resistance of $25\,\Omega/\square$. The thickness of the GaAs substrate was decreased to 100μm by wafer grinding process, and the substrate underneath the hot thermocouple junctions and the matched resistance was removed by via hole etching technology. Fig 6 shows a summary of the fabrication scheme.
4. Conclusions
We have presented a novel structure for microwave power sensor. The novelty of this sensor is that it couples a small portion of the microwave power by the MEMS membrane. In the novel power sensor, the sensitivity of more than 10mV/W, the insertion losses of better than 0.2dB, and the reflection coefficient of lower than -20dB in the X-band frequency range are expected.

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