第 17 卷　第 7 期
2009 年 7 月

光学 精密工程
Optics and Precision Engineering

Vol. 17　No. 7
Jul. 2009

文章编号　1004-924X(2009)07-1656-04

基于单片式微波集成电路的终端式 MEMS 微波功率传感器

许映林，廖小平，田　涛
（东南大学 MEMS 教育部重点实验室，江苏 南京 210096）

摘要：提出了一种基于塞贝克效应的终端式 MEMS 微波功率传感器，该传感器的制作工艺与 GaAs 单片式微波集成电路（MMIC）工艺兼容。利用热电偶检测温度差，生成与微波功率成比例的直流电压，由 GaAs/Au 热电偶串联构成热堆。传感器将电功率转化为热，再间接测量热堆生成的直流电压。采用微机械加工技术，去除了器件底部的 GaAs 衬底，从而减小了热损耗和电磁损耗，提高了灵敏度。测试结果表明，在 0～20 GHz 内，HFSS 模拟的 S_{11}＜－22 dB；测试输入功率为－20～20 dBm 时，频率为 0～20 GHz；在 20 GHz 时，灵敏度高于 0.15 mV/mW；在整个频率范围内，回波损耗低于－26 dB。

关　键　词：MEMS；微波功率传感器；MMIC
中图分类号：TN62；TP212.1　　**文献标识码：**A

Terminating type MEMS microwave power sensor based on MMIC

XU Ying-lin, LIAO Xiao-ping, TIAN Tao
(*Key Laboratory of MEMS of Ministry of Education*, *Southeast University*, *Nanjing* 210096, *China*)

Abstract: On the basis of the Seebeck effect, a terminating type MEMS microwave power sensor fully compatible with the GaAs Monolithic Microwave Integrated Circuits (MMIC) process is presented. A thermocoupler in the microwave power sensor is used to detect the temperature difference and to generate a DC voltage proportional to the microwave power. Then, a series of GaAs/Au thermocouples make up a thermopile. The sensor based on a simple principle converts the electric power into heat and the DC voltage produced by the heat is indirectly measured, so that the output microwave power can be obtained. Moreover, in order to minimize the thermal and electromagnetic losses, the bulk GaAs located beneath the device is removed through micromachining. As a result, the sensitivity of the sensor is improved. Tested results show that the HFSS simulation of S_{11} is less than －22 dB when the sensor measures the microwave power from －20 dBm to ＋20 dBm. The sensor sensitivity is higher than 0.15 mV/mW at 20 GHz, and the input return loss is less than －26 dB over the entire frequency ranges.

Key words: MEMS; microwave power sensor; Monolithic Microwave Integrated Circuit (MMIC)

Received date: 2009-01-20; **Revised date:** 2009-04-30.

Foundation item: Supported by the National Natural Science Foundation of China (Grant No. 60676043); the National High-Tech Research and Development Program of China (863 Program) (Grant No. 2007AA04Z328)

1 Introduction

Microwave power plays an important role in wireless applications and communication systems, so a high performance sensor with high-sensitivity is needed to measure the microwave power accurately and quickly. Thermocouple-based power sensors have been one of the most widely used tools for microwave power detection. These sensors employ a simple principle of conversion of electric power to heat, which is a indirectly measurement. With the development of MEMS technology[1-3], high-precision, low-cost MEMS microwave power sensors are available. By now, various structures of microwave power sensors have been introduced[4-7]. Most of these sensors are fabricated by CMOS processes, while the thermal loss and lossy nature of the silicon substrate at microwave frequencies are considerable. The fabrication of the microwave power sensor is compatible with the GaAs MMIC process. High thermal resistivity and low electromagnetic loss at microwave frequencies can be obtained with the GaAs MMIC process. Micromachining technology is used to realize the selective etching of the substrate beneath the device. By using the MEMS technology and MMIC process, the losses mentioned above are minimized. The most important performance of this kind power sensor is sensitivity which is equal to the ratio of output thermoelectric potential and input microwave power.

2 Principle

The structural diagram of the microwave sensor is shown in Fig. 1. A coplanar waveguide (CPW) feeds the microwave signal to the sensor. The CPW is designed to have a characteristic impedance of $Z=50\ \Omega$. It is terminated with a resistive load that is matched to the impedance. This load absorbs the microwave power and converts it into heat. The increase of the resultant temperature on the load is detected by integrated thermocouples and a DC voltage based on Seebeck effect is generated.

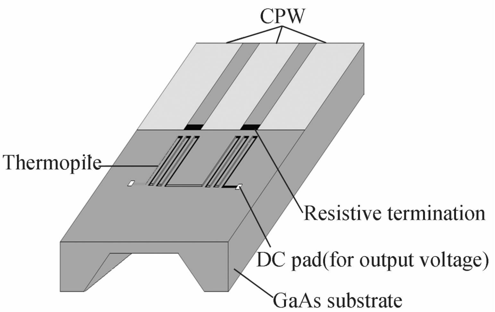


Fig. 1　Structural diagram of microwave power sensor

The output voltage is proportional to the microwave power. In terms of the thermoelectric voltage U and the microwave power P, the output voltage could be given by:

$$U=N\alpha\Delta T=N\alpha P/G\ ,\qquad(1)$$

with N denoting the number of thermocouples, α is the Seebeck coefficient, ΔT is the temperature difference between the hot and cold junctions , and G is the thermal conductance of the thermopile.

The HFSS simulation of S_{11} is shown in Fig. 2. It could be found that the return loss is less than −22 dB up to 20 GHz.

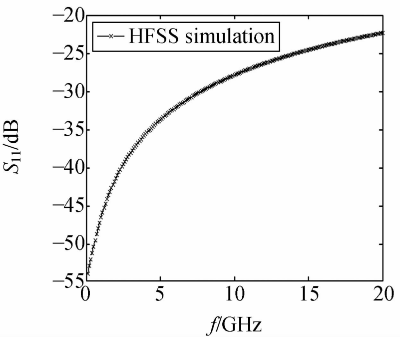


Fig. 2　HFSS simulation of S_{11}

3 Fabrication and measurements

The CPW is made of a 2 μm thick gold layer. The thermopiles consist of gold and n+

GaAs. The Seebeck coefficient of each thermocouple is 100 μV/K. The gold of the thermopiles is made by sputtering of a 0.3-μm-thick gold layer, and the n+ GaAs is made of a 0.25-μm-thick epitaxial layer. The matched load is made by using a liftoff process through depositing of a TaN layer with a square resistance of 25Ω/□. A microphotograph of the microwave power sensor is shown in Fig. 3.

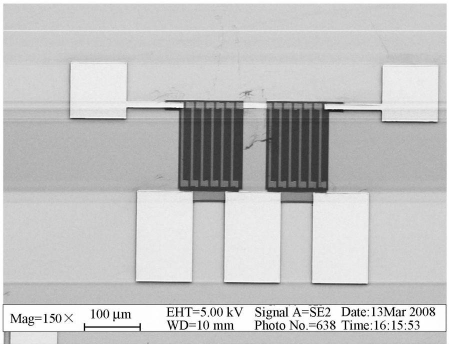


Fig. 3 SEM photo of microwave power sensor

Measurements are performed at frequencies up to 20 GHz. And the testing system contains an Agilent E8257D PSG analog signal generator, an Agilent 8719ES network analyzer, a Cascade Microtech 1 200 probe station for contacting the sensor, and an accurate DC voltage meter. Fig. 4 shows the terminating type MEMS microwave power sensor under test.

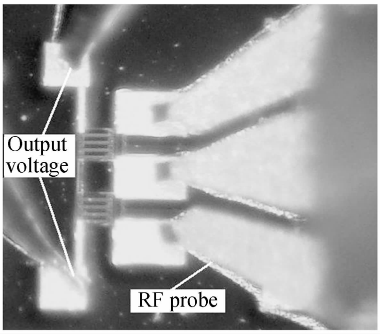


Fig. 4 Microwave power sensor under test

Fig. 5 shows acceptable mismatch error below −26 dB for different frequencies. The sensor has a good RF-DC linearity which could be found in Fig. 6. The microwaves from −20 dBm to 20 dBm at 10 GHz and 20 GHz are applied to the input, respectively, and output DC voltages are recorded. The slope of the 10 GHz is 0.19 mV/mW, and 0.15 mV/mW at 20 GHz.

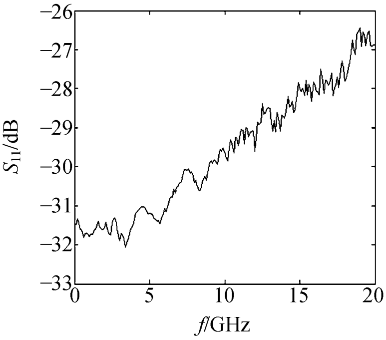


Fig. 5 Input return loss of microwave sensor

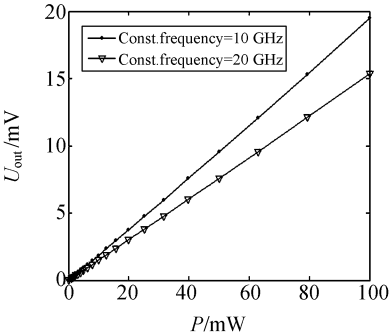


Fig. 6 Input power *vs* output voltage

The frequency response is shown in Fig. 7. The frequency response at constant power 10 dBm is not as good as design demands. In low frequency range, the output is an approximate linear decline. After 15 GHz, the response becomes flat and the outputs are less than those in low frequency range. Perhaps as a result of the

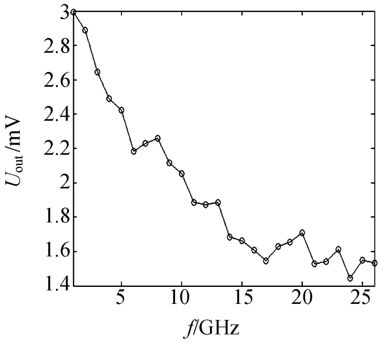


Fig. 7 Frequency response

effect of the fabrication process, the GaAs substrate is not well selectively etched as design, resulting in considerable losses in high frequency range.

4 Conclusions

A terminating type MEMS microwave power sensor based on MMIC is proposed. The measurement results show that the reflection loss is less than -26 dB over the entire frequency ranges and the sensitivity is 0.15 mV/mW at 20 GHz.

References:

[1] ZHANG T, WU Y H, LI H W, *et al.*. Micro electromagnetic actuator with high energy density based on MEMS technology[J]. *Opt. Precision Eng.*, 2007,15(6):866-872. (in Chinese)

[2] WEI X G, JIANG J, WEN ZH M, *et al.*. Optical system design for MEMS based digital sun sensor [J]. *Opt. Precision Eng.*, 2008, 16(8): 1361-1366. (in Chinese)

[3] SHI Y F, SHI Y B, LIU Y H, *et al.*. Sulfur dioxide poison gas sensor based on MEMS laminated microstructure[J]. *Opt. Precision Eng.*, 2008, 16(6):1075-1081. (in Chinese)

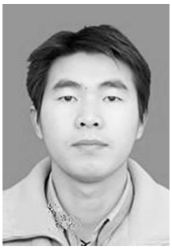
[4] MILANOVIC V, GAITAN M, BOWEN E D, *et al.*. Thermoelectric power sensor for microwave applications by commercial cmos fabrication[J]. *IEEE Electron Device Letters*, 1997,18(9):450-452.

[5] MILANOVIC V, GAITAN M, BOWEN E D, *et al.*. Implementation of thermoelectric microwave power sensors in cmos technology[C]. *IEEE International Symposium on Circuits and Systems*, 1997 (4):2753-2756.

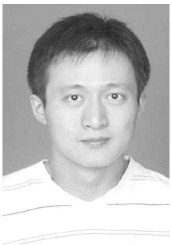
[6] MUTANMBA K, BEILENHOFF K, MEGEJ A, *et al.*. Micromachined 60 GHz GaAs power sensor with integrated received antenna[C]. *Proceedings of IEEE MTT-S Symposium*, 2001(3): 2235-2238.

[7] MILANOVIC V, GAITAN M, ZAGHLOUL M E. Micromachined Thermocouple microwave detector in cmos technology[C]. *IEEE 39th Midwest symposium on Circuits and Systems*, 1996(1): 273-276.

Authors' biographies:



XU Ying-lin (1983－), male, conducts research at the Laboratory of MEMS of the Ministry of Education, Southeast University. His researches focus on RFMEMS and microwave power sensors. E-mail: yinglinx@gmail.com



TIAN Tao (1982－), male, M. S. of the Key Laboratory of MEMS of the Ministry of Education, Southeast University, his researches focus on antennas and microwave power sensors. E-mail: tiantao606@163.com

LIAO Xiao-ping (1965－), male, received his B. S and Ph. D. degrees from Southeast University in 1987 and 1998, respectively. He was a postdoctoral researcher at Hong Kong University of Science and Technology in 2002, where his research focuses on RF SOI power MOSFETs. He is currently a professor in the Key Laboratory of the MEMS of the Ministry of Education, Southeast University. His researches focus on RF MEMS devices and circuits, particularly on RF MEMS switches and microwave power sensors. E-mail: xpliao@seu.edu.cn