Micromachined 60 GHz GaAs Power Sensor with Integrated Receiving Antenna

K. Mutamba, K. Beilenhoff[(1)], A. Megej, R. Dörner[(2)], E. Genc, A. Fleckenstein, P. Heyman[(2)], J. Dickmann[(3)], C. Woelk[(3)] and H. L. Hartnagel

Institut fuer Hochfrequenztechnik, Technische Universitaet Darmstadt, Merckstr. 25, 64283 Darmstadt, Germany

(1) now with United Monolithic Semiconductors S.A.S., BP 46, 91401 Orsay Cedex, France

(2) Ferdinand-Braun-Institut fuer Hoechstfrequenztechnik, Albert-Einstein-Str. 11, 12489 Berlin, Germany

(3) DaimlerChrysler AG Research Center, Wilhelm-Runge-Str. 11, 89081 Ulm, Germany

***Abstract* — A micromachined 60 GHz GaAs power sensor with a monolithically-integrated receiving antenna will be presented. In this sensor configuration thermoelectrical properties of AlGaAs/GaAs heterostructures are used, so that no external dc power supply is needed. First measurements with separate sensor and antenna structures on the same chip have shown a broadband sensor response as well as an excellent matching between the antenna and the sensor input.**

I. INTRODUCTION

Recent efforts on the development of integrated microwave and millimeter-wave sensor system have been boosted by the ever expanding wireless communication technologies such as indoor applications, traffic surveillance, passive portable systems and the military [1]. The advantage of using III-V compounds on the basis of GaAs or InP material systems upon Si stems from:

1) the capability of monolithic integration of the sensor functions with MMICs on the basis of the same materials
2) the possibility of increased sensitivities due to the bandgap engineering, allowing to tune material properties for sensing effects and precise micromachining through selective etching.

The present work reports on the development of a micromachined 60 GHz power sensor. The feeding system consists of an integrated planar dipole-antenna which is used to detect the 60 GHz power. The antenna is matched to the sensor input and the transduction principle is based on the conversion of rf power into thermal power which is then measured by thermoelectrical means. First measurements with separate sensor and antenna structures on the same chip have shown a broadband sensor response with a constant sensitivity in the frequency range up to 80GHz. An excellent matching between the sensor input and the antenna could be reached. This sensor, which does not require a dc power supply, just uses the energy of the received rf signal to be measured and is suitable for field applications.

II. SENSOR DESCRIPTION AND FABRICATION

The sensor consists of a thermally-isolated thin $Al_{0.48}Ga_{0.52}As/GaAs$ membrane region with a matched terminating NiCr (80/20) resistor in which the heat generated by the received rf power is dissipated (Fig. 1). For the used frequency range, a monolithic integration of the sensor and a receiving antenna is possible on the chip surface of $3.5x3.5mm^2$. Selective etching of the GaAs substrate against $Al_{0.48}Ga_{0.52}As$ is used to release the high-thermally resistive 2 microns thick membrane region. This helps to increase the temperature gradient between the center of the membrane where the resistor is located and the rest of the chip which acts as a heat sink. The temperature difference is sensed by a series combination of GaAs/Au-Cr thermoelelements. The latter provides a dc output that is proportional to the effective value of the input rf power. While most of the reported sensor concepts use a 50Ω termination and the corresponding coplanar waveguides, thus offering compatibility to standard MMIC technology, the requirement here is to match the terminating resistor to the dipole antenna [2]-[3]. A matching network to the heating resistor impedance on the membrane is realized with coplanar strip lines. A simplification of the sensor fabrication technology, which involve a top and back side processing of the wafer, can be achieved.

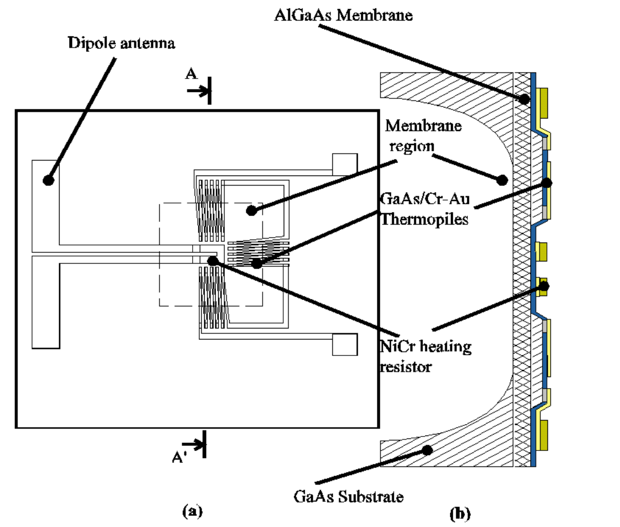

Fig. 1. Top view (a) and enlarged AA'-cut (b) of the sensor. The impedance of NiCr resistor is matched to that of the λ/2 dipole antenna. The hot ends of the thermopiles are located on the membrane in the closed neighborhood of the heating resistor and the cold ends are on the rest of the chip.

Furthermore, the minimum metal cross section of the transmission line helps to keep most of the heating power in the center of the membrane, hence, increasing the sensor efficiency.

The substrate thickness variation along the transmission line has been taken into account in the rf design of the sensor.

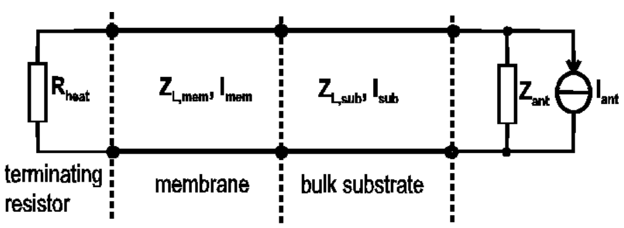

Fig. 2. Equivalent circuit of the sensor. There are two sections of the coplanar strip line connecting the terminating resistor the to the feeding antenna.

This variation gives rise to differences in the propagation characteristics depending on whether the coplanar strip line is on the membrane or on the substrate. Taking this aspect into account leads to the definition of a sensor equivalent circuit consisting of four different elements as shown in Fig. 2. Using HP Eesof 7.1 and Momentum 2.0 as design tools, the dimensions of the equivalent circuit elements have been defined in order to provide the matching between the sensor structures and the antenna. Resistances values between 119 and 125 Ω could be achieved for the target value of 126 Ω for the NiCr terminating resistor. Further considerations on the effects of process variations on the sensor performances included variations in the lateral dimensions of the membrane as well as the etch profiles of the underlying substrate. The simulation results could show a robust behavior of the sensor to variations in the membrane structure.

The wafer design is a flexible one, allowing the use of standard MESFET or GaAs-based MEMS heterostructures with additional layers for membrane and etch stop function [4]. The used GaAs wafer was MOCVD-grown by Epitronics Co. The layer structure is shown in Table 1.

Table 1. Wafer structure for the sensor

Layer No.	Material	Thickness [nm]	Carrier Conc. [cm^{-3}]
7	GaAs	100	n^+ 5.0E18
6	GaAs	500	n 2.0E17
5	GaAs	1000	undoped
4	$Al_xGa_{1-x}As$	20	undoped
3	$Al_{0.48}Ga_{0.52}As$	1000	undoped
2	$Al_xGa_{1-x}As$	20	undoped
1	GaAs	50	undoped
Semi insulating GaAs substrate			

The 2 µm thick membrane is mainly formed by the combination of the layer 5 and 3 where the undoped $Al_{0.48}Ga_{0.52}As$ layer also acts as etch stop for the selective etching. The thin AlGaAs grading layers (20 nm) allow for a smooth variation of the lattice constant between $Al_{0.48}Ga_{0.52}As$ and GaAs. With an average sheet resistance of 54 Ω/☐, Seebeck coefficients of up to 300 µV/K can be expected from thermoelements made of GaAs mesa and Cr/Au were the mesa is a parallel combination of the n-doped channel layer and the n+ cap layer [5]. The later also serves for the ohmic contact formation. Higher thermocouple sensitivities are possible with reduced doping or with AlGaAs-based mesa but this happens at the cost of a reduction of the signal to noise ratio due to the high resistivities of the thermoelements [6]. This is not desirable for this application where small power level are

available. Fifteen thermocouples are connected in series to increase the output voltage.

The sensor fabrication technology consists of a front-side processing followed by a back side step.

Electrical and thermoelectrical functions including the antenna structure are implemented during the processing of the front-side. The used steps are similar to those described in [3] and an electroplated Au layer of 3 µm thickness has been defined for the antenna and the transmission line structures.

The back side processing helps to define the membrane region. Here, the wafer is first thinned down to a final thickness of 150 µm by means of a mechanical-chemical polishing process and passivated. The membrane is selectively etched using a spray etching technique with a NH_4OH/H_2O_2 solution. The thickness of the final membrane is homogenous with the smoothness of the epitaxial interface.

II. MEASUREMENT RESULTS

Measurements have been carried out on a device design where a cut is made in the transmission line to allow for a separate characterization of the sensing and the antenna structures. Additional line segments have been introduced to form GSG electrode configuration for on-wafer measurements.

A. Sensor Sensitivity and dynamic range

The sensor output at different power levels shows a constant sensitivity of about 12mV/mW (Fig. 3). The noise equivalent power for the 20 kΩ thermopiles correspond to a signal to noise ratio of $7.1x10^8$/W.

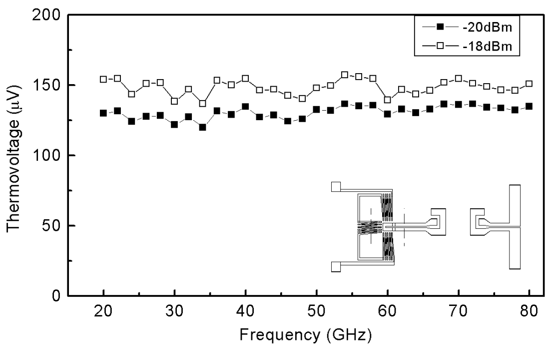

Fig. 3. Sensor output shows a constant sensitivity of around 12 mV/mW on an broad frequency range. The inset shows the modified line configuration (GSG) for on-wafer characterization.

The dynamic range is here only limited by the available and accurately defined power for the frequency range. Due to the small heat capacitance of the membrane structure a time constant of 2 ms has been measured. Burnout could be observed at a dc power above 55 mW. This takes place in form of a degradation of the NiCr terminating resistor.

B. Scattering parameters and matching

The results of the scattering parameters for the sensing structure and the antenna are shown in Fig. 4. The deviation in the matching is attributed to the addition of the line segments (inset Fig. 2).

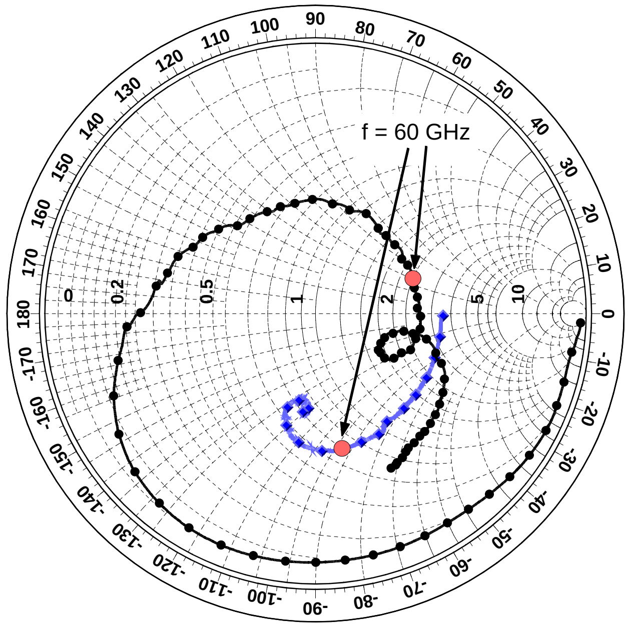

Fig. 4. Scattering parameters (s_{11}) of both the sensing structure (line and diamonds) and the antenna (line and circles) for the frequency range between 0.15 and 105 GHz. The deviation in the matching is arising from the additional line segments.

V. CONCLUSION

A fully passive GaAs 60GHz power sensor with integrated receiving antenna has been demonstrated. The broadband response of the sensing effect as well as the obtainable matching with the antenna makes the device concept suitable for various applications ranging from on-chip gain control of rf–amplifiers output power to simple and cheap rf power detectors. Experiments for a direct detection of the radiated power will help to characterize the overall performance of the sensor and provides orientations for the device optimization.

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