GaAs Monolithic Integrated Microwave Power Sensor in Coplanar Waveguide Technology

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Abstract

We present the fabrication technology, theoretical and experimental results of a novel MMIC compatible broadband power sensor. With a 50Ω coplanar waveguide design, integrated AlGaAs thermoelectric sensor and GaAs bulk micromachined membrane for increased sensitivity this sensor is capable of detecting RF power with a sensitivity of 1.1V/W without any waveguide coupling structure.

Motivation

Bolometric microwave and mm-wave power sensors integrated with GaAs-MMIC have not been reported so far. Such sensors may be used for the evaluation of reflection coefficients, power levels in microwave circuits or for the realization of an integrated network analyser.

Different types of micromachined thermal sensors have been reported on silicon [1], [2]. These sensors are impedance matched to the circuit and convert 100% of the RF power into heat. Such sensors are not suitable for monitoring the microwave power transmitted between different stages of a MMIC amplifier. Firstly, a coupling structure would be needed to extract a certain fraction of the transmitted power. Hybrid mounting would be very inefficient for this purpose. The insertion loss would increase when coupling structures are introduced. Finally, the frequency of operation would be limited by the operational range of the coupler. A monolithically integrated sensor with a broadband low reflection coefficient is therefore highly desirable.

This paper demonstrates a sensor that meets the above mentioned requirements. It can be applied for power monitoring, gain control or circuit protection purposes. The sensor utilizes the inherent losses of the CPW for power monitoring. It consists of a 50Ω coplanar waveguide (CPW) that is positioned on a 1μm thick AlGaAs membrane (fig. 1). The membrane is needed for thermal isolation. The center conductor has thermal contact to the membrane and the metallic losses are converted into heat resulting in a measurable temperature increase. Since the ground conductor suspends the membrane as an air bridge a thermopile - lying on the membrane - monitors directly the temperature of the center conductor. The output voltage of the thermopiles is proportional to the transmitted power.

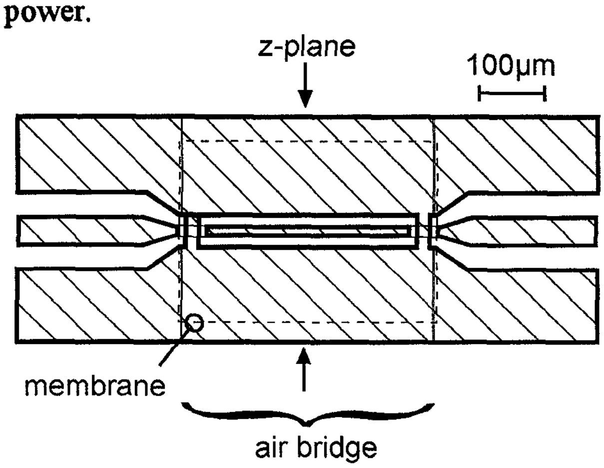

Fig. 1: Geometrical configuration of the CPW structure.

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The concept of membrane supported CPW has already been demonstrated on Si substrate for the purpose of microshielding [3]. We will demonstrate here, that an AlGaAs-membrane supported CPW provides high circuit performance capabilities. This will be verified by measurements and finite-difference computation [3]. Together with the fact that the technology of this sensor is adapted from standard MESFET technology with only one final micromachining etch step this sensor has the capability to be used in MMIC.

Sensor Design and Technology

To detect the transmitted power of a CPW is certainly difficult without affecting the system. Therefore, making use of an intrinsic effect of ohmic losses in the metal conductors of the CPW provides a very elegant solution. These losses will result in Joule heat which is dissipated in a conventional GaAs based CPW. To detect this heat the dissipation must be controlled.

The high thermal resistivity of $Al_{0.48}Ga_{0.52}As$ [5] - as used here - is advantageous in conjunction with the fabrication of membranes as thin as 1µm. The realization of membranes with thermal resistances of several thousand K/W [6] is sufficient to transfer µW into measurable temperatures. The temperature can easily be measured with integrated GaAs/AlGaAs thermocouples that can be cascaded to reach sensitivities of several mV/K.

Finite difference simulations have shown that about 70% of the losses are caused by the metallic losses of the center conductor. Hence, the temperature should be measured in the vicinity of the center conductor.

Figure 1 shows the design of the 3µm thick gold plated CPW line that was used for the sensor. Figure 2 shows a schematic cross-section through the sensor structure. The according process steps are listed.

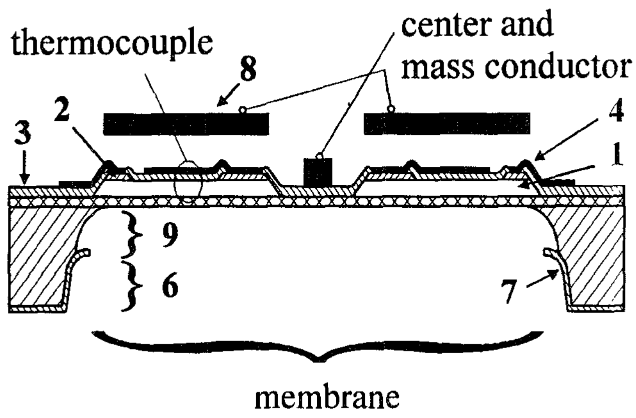

Fig 2.: Schematic technology cross-section through the z symmetry plane (see figure 1). The enumeration of the layers corresponds to the technology steps: 1) mesa etching of thermopile; 2) ohmic contact (Ni/AuGe); 3) Si_xO_yN PECVD passivation; 4) Cr/Au interconnects; 5) thinning of the wafer; 6) isotropic pre-etching; 7) Si_xO_yN back side deposition; 8) Au electroplating of the CPW; 9) selective spray etching (stops on membrane).

The tapered ends of the CPW are used for on-wafer probing. The two ground conductors are connected via two air bridges to suppress parasitic modes. In order to avoid a thermal short-circuit of the ground metallization, it is lifted 3µm above the membrane while the center conductor is in contact with the membrane. The dimensions of the CPW are choosen such that a 50Ω line is obtained: center conductor width w=17/47µm, slot s=16.5/36µm and ground w_g=150/115µm (taper/membrane) wide, respectively.

The 3µm air gap between ground metallization and membrane - fabricated with an air bridge technique - is used to place the thermopiles. Figure 3 shows the surface of the sensor prior to the plating of the CPW. Side by side of the center conductor the thermopiles of 2x15 $Au/Al_{0.40}Ga_{0.60}As$-thermocouples (0.7µm thick, doped $N_D=10^{18}cm^{-3}$ are visible. $Al_xGa_{1-x}As$ has a significant Seebeck coefficient depending on the AlAs mole fraction x and the type and level of doping [7]. The thermopiles have to measure the temperature difference with respect to the bulk of the chip. The distance between center conductor and hot end of the thermocouples is the same as the slot width of the CPW. This results in minimum impact of the thermopiles on the wave propagation.

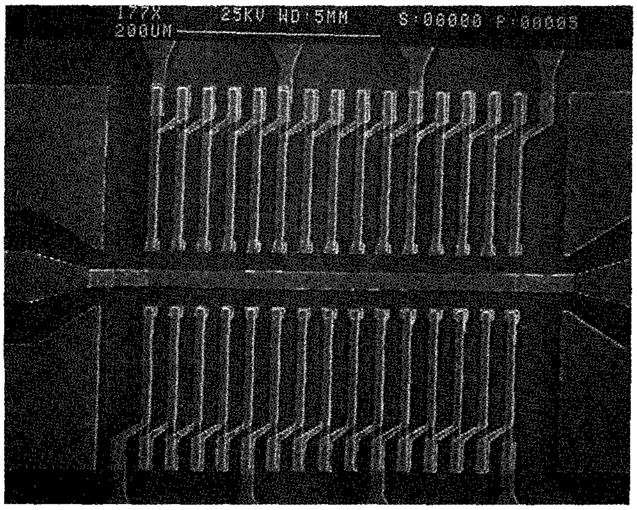

Fig. 3: SEM picture of the sensor before plating of the CPW and etching of the membrane. On both sides of the center conductor the 2x15 Au/$Al_{0.40}Ga_{0.60}As$-thermocouples are visible.

Since the etching of the membrane relies on the chemical selectivity between GaAs and AlGaAs the quality of the membrane is determined by the epitaxial AlGaAs layer. The membrane thickness homogeneity is excellent and the smoothness is that of the epitaxial interface.

The final membrane etching, that takes about 20min (fig. 2 (9)), does not attack the surface electronics because they are sealed with wax. This technology can also be applied to standart HEMT or MESFET foundry processes, provided an AlGaAs-buffer layer is used.

Theoretical Evaluation of the Membrane CPW

To validate the quality of the CPW with and without membrane full network analysis from 45MHz to 26.5GHz has been performed. We have simulated the scattering parameters (fig. 4) of the complete membrane structure as shown in fig. 1 with a three-dimensional finite difference method in frequency domain (F3D) [8], which was extended to include losses [4].

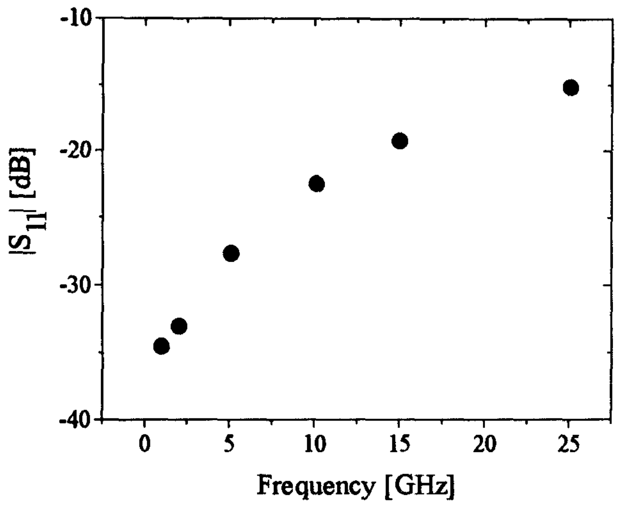

Fig. 4: Simulated results for the reflection coefficient for CPW on a membrane.

The presence of the thermopiles underneath the mass conductor has been neglected in the simulation. The reflection coefficient of the membrane CPW increases with frequency as expected. The reflection coefficient is smaller 0.2 over the frequency band up to 26.5GHz and agrees very well with the experiment. An improvement of the frequency characteristics of the reflection coefficient with similar thermal properties is possible.

Microwave Measurements with the Sensor

The sensors have been contacted with on-wafer probes and calibrated with a HP8510B network analyzer (fig. 5). The average sensitivity in the frequency range up to 14GHz is (1.11+-0.03)V/W. The jitter in the measurement points is due to the uncertainty in the reference power level. Figure 5 also demonstrates the broadband characteristic of the sensor - one of its major advantages.

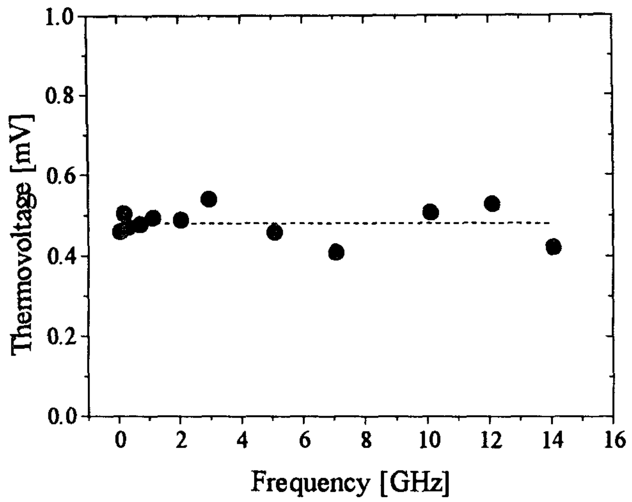

Fig. 5: RF power calibration of the power sensor. The transmitted power was held constant 0.43mW. The average sensitivity is 1.11V/W.

The resistance of the thermopile that was used for these measurements was 301kΩ. Since thermopiles present a voltage source it is commonly accepted to make only Johnson noise responsible for the noise figure. Consequently, the noise equivalent power was calculated to be $11 nW/\sqrt{Hz}$.

We have measured the step response of the sensor to be about 1ms which should be sufficient for most monitoring applications.

Since thermal time constants are determined by heat capacitance and thermal resistivity there is always a trade-off between sensitivity and time response.

Conclusions

We have demonstrated a RF power sensor that is realised as CPW on GaAs. The advantages of this device are the broadband power detection with low insertion loss and low reflection coefficient, a high sensitivity of 1.1V/W, and the MMIC compatibility, that allows integration with active components for various applications.

Acknowledgement

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