Novel RF Power Sensor on Si Rod Waveguide

A. Generalov[1], D.V. Lioubtchenko[1], J. Mallat[1], V. Ovchinnikov[2], and A.V. Räisänen[1]
[1]Department of Radio Science and Engineering / SMARAD, Aalto University School of Electrical Engineering, P.O. Box 13000, FI-00076, AALTO, Finland
[2] Micronova Nanofab, Aalto University School of Electrical Engineering, P.O. Box 13500, FI-00076, Finland

***Abstract*- In this paper a new type of RF power sensor, based on the metal antenna-like structure employed as a bolometer, is presented. It consists of an antenna-like structure integrated into an mm-wave range Si dielectric rod waveguide with thin film deposition technology. Numerical simulations of temperature distribution as well as HFSS were performed and prototype at frequencies 80-140GHz was tested.**

I. Introduction

Dielectric rod waveguides (DRW) are successfully used as basic feeders in the millimeter wave integrated circuits [1]. Historically, bolometer power sensors play a big role in the power measurements. Thermal bolometers are widely used in the mm and sub-mm wave range, particularly in a form of a thin membrane [2,3]. A bolometer power sensor detects the heating caused by absorption of RF or millimeter wave power. The role of the absorbing material is usually played by a metal with a known dependence of resistance vs. temperature, which is conventional.

Bolometers have proved themselves in radio astronomy, where bolometers are widely used in the mm and sub-mm wave range [2]. In [4] a bismuth microbolometer for millimeter-wave and far-infrared detection was demonstrated. A power sensor based on the electron heating effect in *n*-Si is presented in [5]. Bolometers on thin dielectric membranes for use as wideband THz power meters are described in [3]. A 60 GHz bolometric power sensor based on a planar dipole antenna presented in [6]. Power is measured by thermoelectrical means in GaAs/Cr-Au thermopiles. Another power sensor based on thermoelectric effect in AlGaAs presented in [7].

One can see that bolometric power sensors successfully used at millimeter wavelengths. However, described power sensors are complicated and hard to fabricate. Power sensors based on thermoelectrical effects in semiconductor heterosctructures usually have limitations of maximum power applied about 55 mW. Some power sensors are compatible to work with high powers only in the pulse regime. Therefore a reliable, simple, cheap and wide range power sensor is of interest. We present in this paper a novel design of a bolometric power sensor which is integrated into a Si DRW.

II. Design

A metallic "antenna" structure absorbs mm-wave power and is heated, which cause a change of its resistivity. The sensor prototype is presented in Fig. 1. The reference resistance is a small stripe of metal which is thermoisolated from the bolometric "antenna" but not from the substrate. Thereby, the reference resistor can detect the heating effect caused by losses in the Si DRW and changes in the environment not related to the absorption in bolometric "antenna". The scheme is designed for 4 wire measurements to improve the precision of the measurement of the reference resistor and bolometer. The width of the power sensor layout is less than 1.2 mm, which allows to integrate it into a mm-wave range DRW [1].

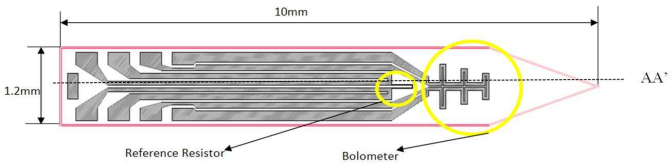

Fig. 1. Power sensor prototype.

III. Fabrication process

The fabrication of the power sensor has been done using silicon dry etch on a high-resistivity silicon substrate. Fabrication steps are shown in Fig. 2. The whole structure contains a sensor chip and a cover chip; they were bonded with SU-8 after fabrication individually.

In order to have a thermal isolation of "antenna" from the reference resistance and substrate a membrane is introduced. The membrane is fixed to Si DRW only by one edge, i.e. it is a cantilever. This design significantly simplifies the fabrication process of the sensor. Elements of the bolometer "antenna" and the reference resistor are placed on top of the cantilever. Si under the cantilever is etched, so that bolometer "antenna" has an air gap for thermal insulation purposes.

In Fig. 3 SEM images of SiO_2 cantilever cut by plane AA' (see Fig. 1) are shown. After 40 minutes etching in ICP-RIE gap depth and lateral undercut reach 80 µm and 60 µm, respectively. The lighter color between gaps shows long channel along symmetry axis of the antenna.

Fig. 2. Fabrication steps of a power sensor.

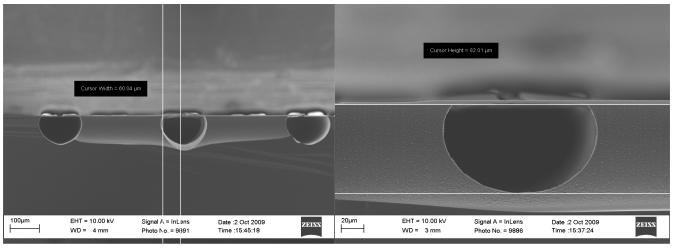
Fig. 3. SEM images of 1 µm thick SiO_2 cantilever cut by AA' plane (See Fig. 1) at different magnifications. Left: three arms of metallic antenna with etched gaps (lateral undercut is 60 µm); Right: central arm (depth of etching is 82 µm).

IV. Thermal simulation

To compare the efficiency of the thermal isolation, simulations with the help of COMSOL Multiphysics 3.5a have been performed for two bolometer designs. In the first one a polymer film (PTFE) is used as a base of the metallic antenna, providing thermal isolation. The second design with a cantilever has been described earlier. The thermal fields for both variants are shown in Fig.4. In both simulations it is supposed that mm-wave power 0.1 mW is dissipated in the metal element. The cooling only by thermal conductivity from metallic antenna to Si DRW is taken into account. One can see in Fig. 4 that maximum overheat of the PTFE film and air gap isolated metallic antenna is 0.05 C and 0.35 C, respectively. Additionally, the film isolated bolometer is slower, as it can be seen in Fig.5a, where time dependences of temperature in the hottest points of the antennas after switch on of RF power are given. Temperature is saturated after 0.07 s in the film bolometer, in comparison with 0.03 s in the case of the cantilever one.

Optimal values of the gap and lateral undercut for the cantilever sensor are found on the base of simulations. The results are shown in Fig. 5b and demonstrate that increasing of both parameters improves sensor functionality. At the same time, technologically acceptable value for undercut is about 50 µm and it is already provides reasonable overheat. That is why experimental samples are fabricated with gap and undercut 50 µm.

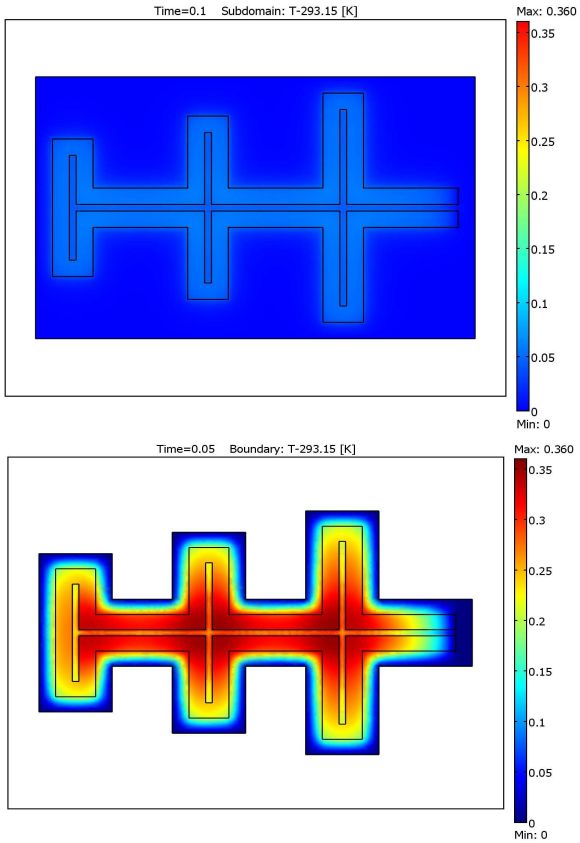

Fig. 4. Overheat temperature distributions of the bolometers with different thermal isolation: Top: 50 µm PTFE layer; Bottom: 50 µm air gap and 1 µm thick SiO_2 cantilever (undercut is 50 µm).

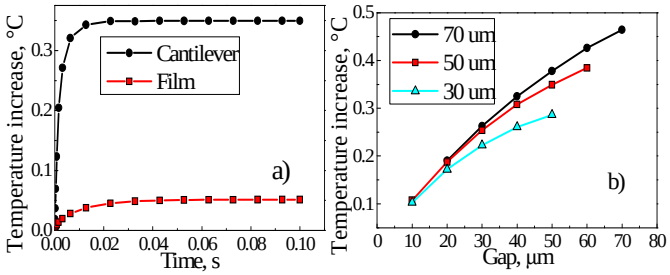

Fig. 5. a) Transient curves of the temperature in the hottest points of the cantilever (black line) and film (red line) variants of sensors; b) Dependence of overheat in the hottest point on gap for different lateral undercuts.

V. Measurements

A measurement scheme of the experimental setup is shown in Fig. 6. HP 8510 Vector Network Analyzer has been used to generate power at frequencies of 85 – 95 GHz. Alteration of power is made with an attenuator.

Image of the power sensor prototype ready to be inserted into a WR-10 waveguide is shown in Fig. 7. The device is connected to a HP 3478A multimeter. The power sensor is inserted inside the end of a WR-10 waveguide.

Measurements have been performed for two different samples with codenames “Big” and “Small”. Sample “Big” is designed for measurements in the 75 – 110 GHz range and sample “Small” is designed for measurements in the 110 – 170 GHz range. The resistances of the devices have been measured at 95 GHz. S_{11} is better that -17 dB for each sample at 95 GHz. Such small value appears due to the size of DRW, which is 1.2x0.6 mm instead of 1.0x0.5 mm [1].

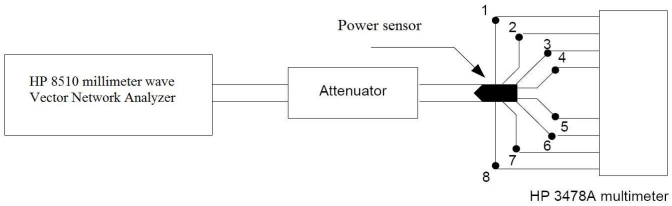

Fig. 6. Experimental scheme.

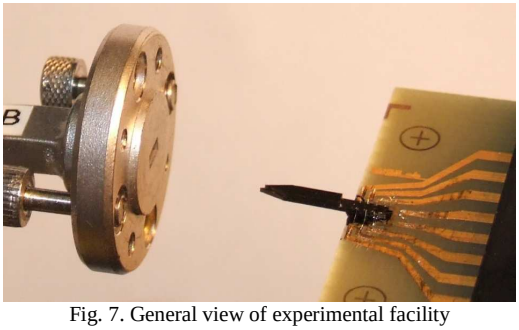

Fig. 7. General view of experimental facility

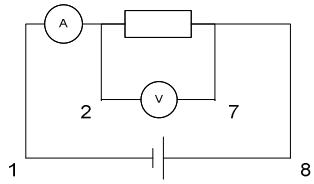

Fig. 8. Equivalent scheme of measurement.

Measurements have been carried out by a 4 wire method. Through one pair of contacts current is generated and through another pair the voltage drop is measured. These measurements are carried out automatically with HP 3478A multimeter. Equivalent scheme of 4 wire measurements for contacts 1-8; 2-7 is shown in Fig. 8. The amount of current generated by the HP3478A multimeter is 1 mA, which gives bolometer constant DC heating and does not affect mm range power heating. Results of 4-wire measurements for samples "Small" and "Big" are shown in Fig. 9. The horizontal axis shows the scale for power, applied to the waveguide. The vertical axis shows the scale for quantity $\Delta R=R-R_0$, where R is resistance at applied power, R_0 is resistance at P=0. Value of R_0 for sample "Small" is 1.81131 kΩ and for sample "Big" is 1.93429 kΩ. One can see that dependences of resistances on power are linear.

The same 4-wire measurements were carried out for both samples at 120 GHz and 146 GHz with a Gunn oscillator power source. Maximum power, generated by Gunn oscillator is 17 mW at 120 GHz and 5.5 mW at 146 GHz. The power is attenuated by the same attenuator as in previous case. Results of measurements are shown in Figs.10-11.

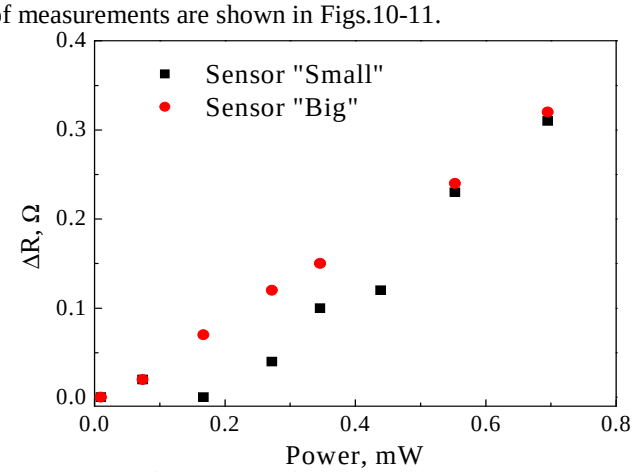

Fig. 9. Results of measurements for sensors "Small" and "Big" at 95 GHz.

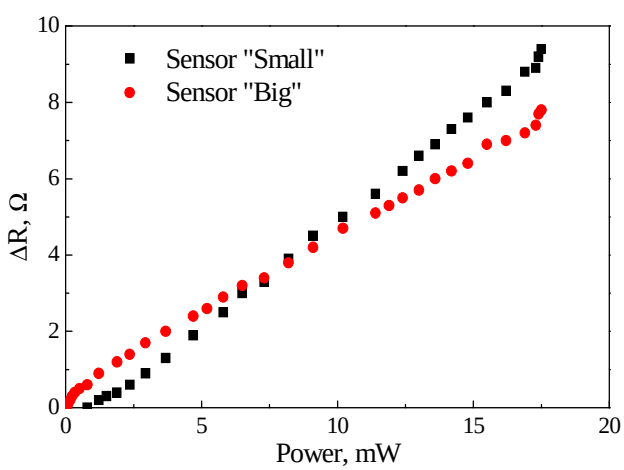

Fig. 10. Results of measurements for sensors "Small" and "Big" at 120GHz.

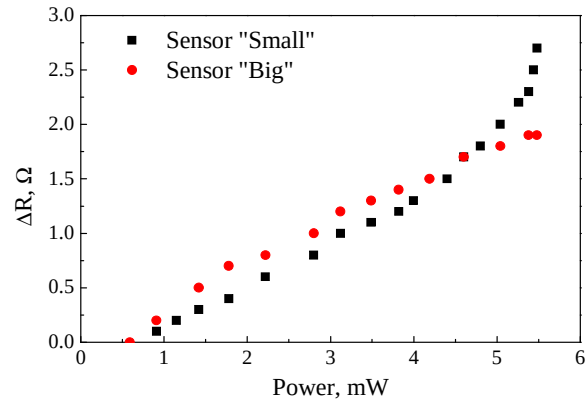

Fig. 11. Results of measurements for sensors "Small" and "Big" at 146 GHz.

One can see from Figs. 9 - 11, that the resistance of the bolometer antenna changes on the power considerably. That means that the antenna absorbs power as it is designed to.

The power sensor has also been tested with a DC power applied up to 200 mW showing no signs of burnout or degradation, which can be considered as a good tolerance to high power.

According to thermal simulations for the sample "Small" 0.1 mW power gives antenna approximately 0.28 °C temperature increase, which corresponds to 1.8 Ω resistance change. Measurement results show 0.5 Ω resistance change, which can be considered as a good correspondence between measurements and simulations. The reason for the difference is unknown part of total waveguide power absorbed in the metallic antenna.

VI. Conclusions

Prototypes of a power sensor with reasonable sensitivity have been made using standard semiconductor technology. Prototype devices are designed for the 75 – 110 GHz and 110 – 170 GHz frequency range. Sensitivity of devices is about 0.5 Ω/mW according to tests at 95, 120 and 146 GHz. Presented power sensor has potential for use in future applications and devices.

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