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Fabrication and characterization of a microheater on GaAs for gas sensors

INTRODUCTION

Metal oxide gas sensors generally work in a high temperature mode that is required by the chemical reactions between molecules of the specified gas and the surface of sensing material. High temperature gradients between the active area and its colder surrounding cause heat losses like conduction through bulk substrate material, convection in air from all exposed surfaces and radiation. Power consumption of gas sensors prepared using thick layer technology is in the range from 200 mW to 1 W due to their excessive thermal mass. If we want to use them in portable applications, these values are still too high. In addition to low power consumption, a uniform temperature distribution in the active area is required to ensure equal sensing properties of the whole surface. Mechanical stability and fast response belong to very important parameters that cannot be neglected. All aforementioned requirements are met by micromechanical structures, where the sensing layer is placed on a suspended thin dielectric membrane prepared by a micromachining process.

In the past few years, new developments in substrate technology and strong research in the preparation of sensing materials have opened the possibility of battery operated low power hand-held gas sensor devices [1,2]. Integration of gas sensitive metal oxide layers in standard microelectronic processing was achieved and led together with the use of micromachining steps to metal oxide gas sensors. For the fabrication of low power sensors, the substrate plays an important role. Typically, silicon, silicon dioxide or silicon nitride membranes supported by a silicon wafer have been used as substrates. Gallium arsenide-based MEMS devices are an attractive alternative to the well developed silicon-based MEMS. These devices have potentially significant future applications in the areas of high speed sensor systems, in extreme temperature conditions, applications requiring radiation hardness and high-performance multi-functionality [3,4].

We present the fabrication and characterization of a microheater on GaAs substrate for potential use as a low loss microheated NiO gas sensor.

DEVICE FABRICATION

The model device structure was fabricated on a double side polished (100) GaAs wafer. The thickness of the GaAs substrates was 300 μm. The basic technological steps for the device fabrication, shown in Fig. 1, can be summarized as follow:

a) A 20 nm thick TiN adhesion layer followed by 200 nm of Pt was deposited by magnetron sputtering and lift-off process. The heater structure was meander type and was situated directly on the semiinsulating GaAs substrate. The resulting resistance of the heater was in the range from 63 to 71 Ω.

b) Organic polyimide PI 2571, 3 µm thick, was prepared as an electrical insulator between the heater and the electrodes by spin off. Then, the contact opening was made by dry etching in oxygen through the insulating layer.

c) TiN/Pt (20 nm/200 nm) intedigited electrodes and bonding pads were patterned by lift-off and deposited by magnetron sputtering as for the heater. The width of electrodes was 150 μm and the separation between them 120 µm. After annealing at 400ºC the stabilization of the electrodes was obtained.

d) The NiO gas sensing layer (150 nm) was deposited onto the the microheater by reactive magnetron sputtering.

e) An etch mask was patterned at the back of the substrate and a window in the Ni layer was defined. In fabrication of GaAs membranes, the basic step was to bulk etch the back GaAs wafer through the Ni mask using selective reactive ion etching in CCl_2F_2.

The total number of masks used in the process was 6. After this process the GaAs wafer was diced, chips were mounted on TO package and four wire bonds were made (two for the heater contacts and two for the electrodes contacts). The obtained sensor structure is shown in Fig. 2. It was characterized by good mechanical integrity and was compact. SEM observation and EDX analysis revealed a uniform morphology and homogeneous dispersion of elements on the surface of the sensor structure (Fig 3). No defects were observed in material distribution in the analyzed thin film sensor structures. We found that the surface morhology examined by AFM was very smooth with a small value of the average roughness (Fig. 4).

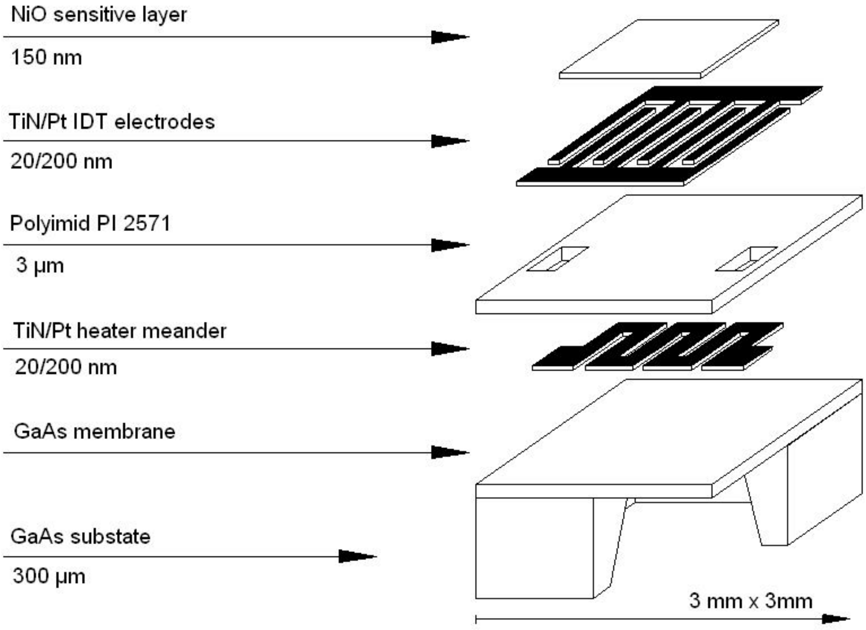

Fig. 1: Process sequence of the gas sensor structure on GaAs.

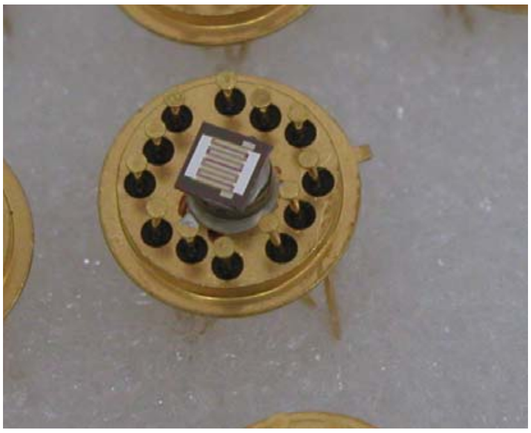

Fig. 2: The photo of gas sensor structure on GaAs and mounted into TO8 package.

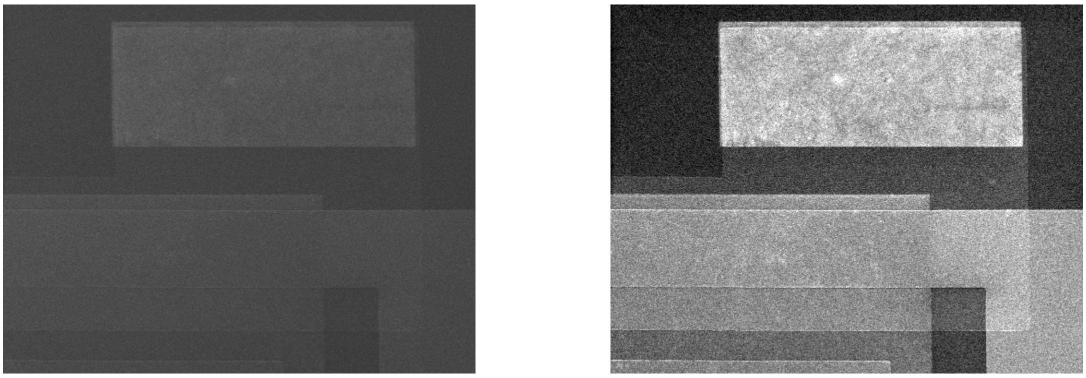

Fig. 3: SEM image of sensor structure and calculated element distribution by CAMEO programme from EDX analysis.

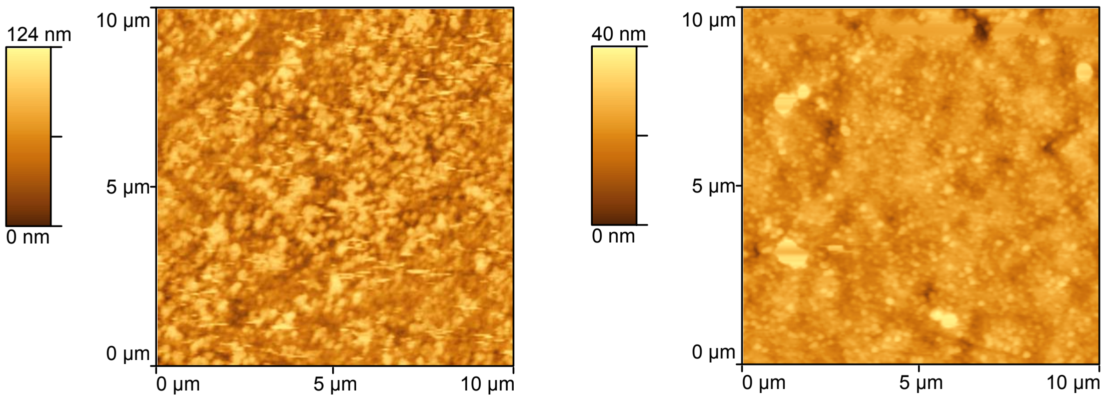

Fig. 4: AFM images showing the surface of Pt-GaAs and PI on Pt-GaAs.

MICROHEATER CHARACTERIZATION

Electrical characterization of the thin film Pt microheater was made by measuring I-V characteristics in a wide temperature range (T=300÷480K). Through these measurements we could investigate the microheater linearity and determine its temperature dependence of resistance. Typical measured I-V characteristics are shown in Fig. 5.

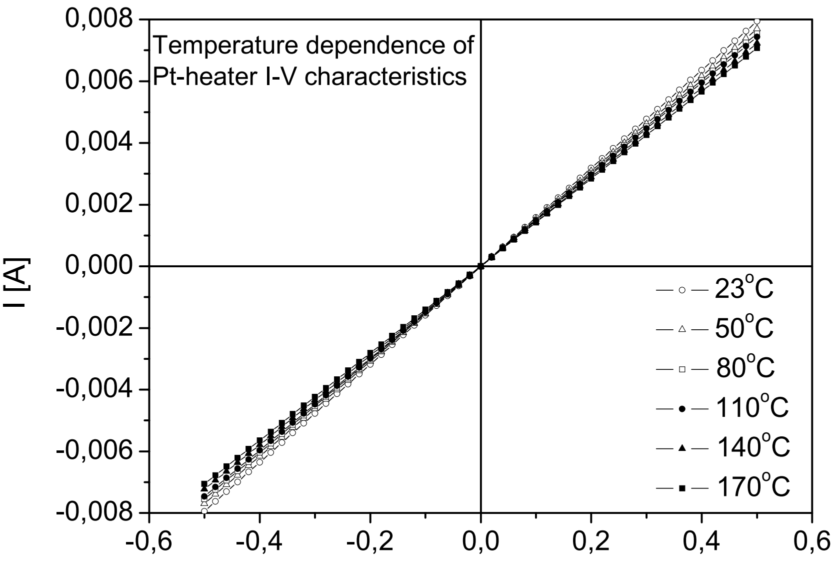

Fig. 5: I-V characteristics of Pt micro heater at different temperature values.

The measurements were realized in a low-voltage region (-0.5V < U < 0.5 V) to attenuate the effect of self-heating. The highest achieved value of power dissipation was approximately 4 mW. The temperature dependence of extracted micro heater resistance values are plotted in Fig. 6. In the measured temperature region (T = 20÷180°C) the Pt microheater resistance exhibits values in the range R = 63÷71 Ω with a positive temperature dependence of resistance 0,05055 Ω/°C.

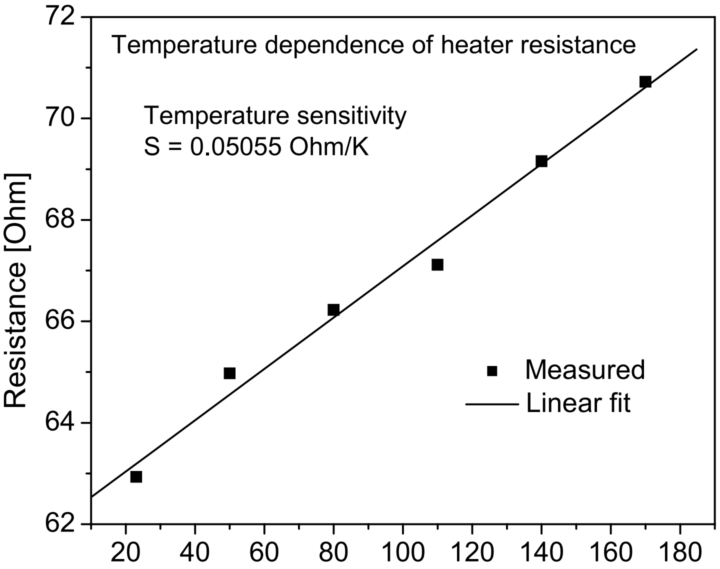

Fig. 6: Microheater resistance temperature dependence.

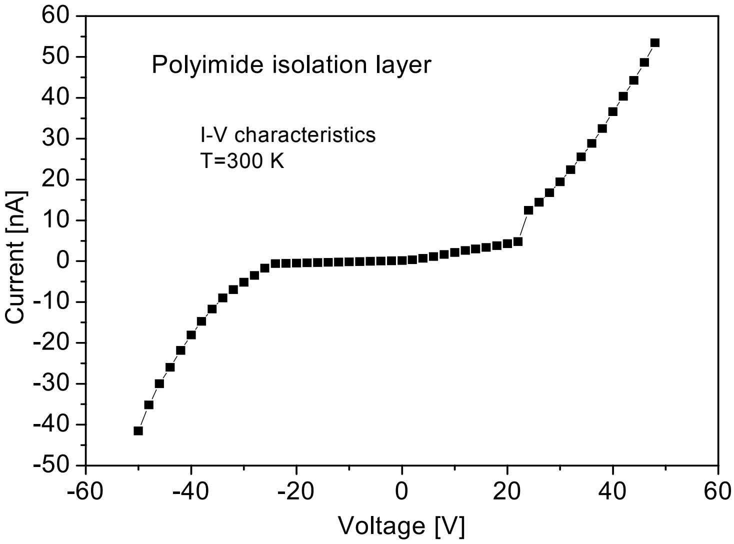

Fig. 7: I-V characteristic of polyimid isolating layer.

Electro-isolating properties of the polyimid layer separating the heating element from sensing interdigitated electrodes were also investigated. It has to be mentioned that the designed SiC isolating layer was substituted by a polyimid layer. Optimal fabrication properties of SiC layers are still a point of our research. Electro-isolating properties of the polyimid layer are optimal for this application, but its low thermal conductance values can significantly decrease the electro-thermal conversion effectivity of the sensor. When measuring the I-V characteristic of MIM (metal-insulator-metal) structure with vertical contacts arrangement (heater contacts and IDT contacts) in the voltage region ± 50 V, no electrical breakdown was not observed (Fig. 7).

The gas-sensitive NiO layer formed on the set of intedigitated electrodes in the configuration of MIM structures was characterized also by measuring the I-V characteristics in the sensor operating temperature range (T=300-480 K). The obtained I-V characteristics are shown in Fig. 8. As it can be seen from plotted curves, NiO layers show symmetric characteristics depending on voltage polarity and their conductivity increases with a rise in temperature. Typical current changes of MIM structures measured at a constant voltage of 20 V are shown in Fig. 9. The exponential temperature dependence of current through the planar MIM structures indicates a semiconducting nature of NiO layers. The dominating mechanism of electrical conductivity of layers was not investigated. We suppose that the temperature sensitivity of NiO thin layers conductivity could be directly used in the study of electro-thermal conversion of the sensor structure. Then the MIM structure can work as a temperature sensor. This enables direct temperature measuring (in situ) on the NiO layer surface at a defined power dissipation in the microheater.

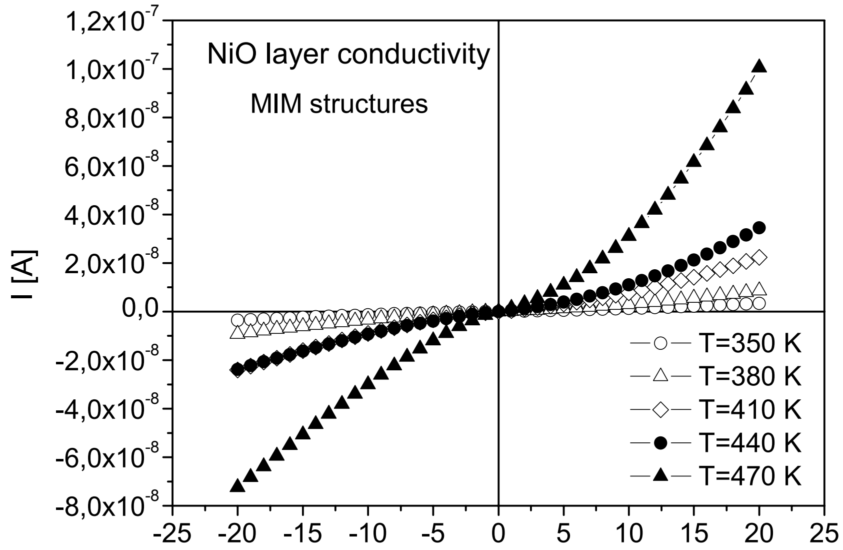

Fig. 8: I-V characteristics of NiO layers (planar MIM structures) at different temperatures.

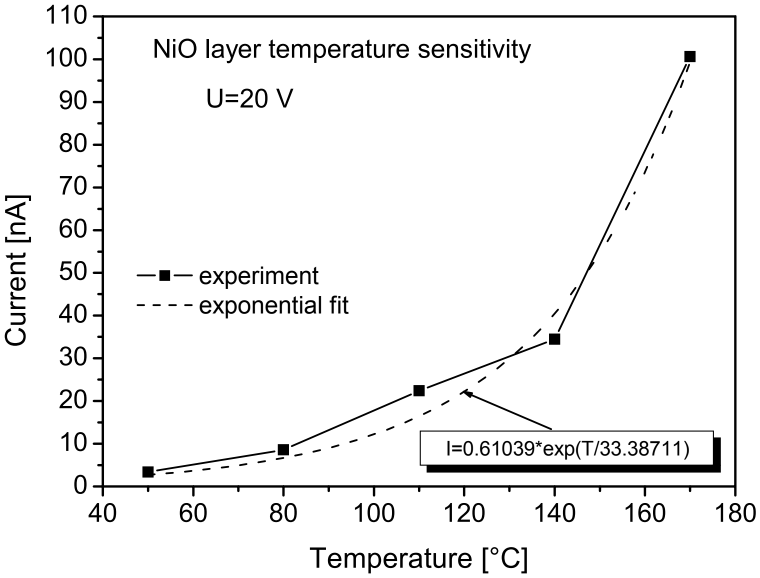

Fig. 9: Temperature dependence of current in NiO layer (MIM structure) at constant voltage.

We have to mention that the model sensor structure was designed for quality testing of single technological process steps (levels) and several selected sensor properties. Therefore the electro-thermal conversion effectivity (achievable thermal resistance values) is not significant since it is not possible to eliminate thermal loss, especially in the GaAs substrate. Despite this, it is important to analyze conversion effectivity of this structure for comparison with the final micromechanical sensor structure. During the investigation of conversion effectivity, the MIM structure was connected to a constant voltage source (U=20 V) and current changes were measured depending on the power dissipation from the thin film microheater. Figure 10 demonstrates measured current dependence on power dissipation (P-I conversion). According to previously measured and defined exponential current dependence on temperature (Fig. 9), the P-I conversion characteristic in Fig. 10 can be directly transformed to P-T conversion characteristic shown in Fig. 11. P-T conversion characteristic demonstrates direct correlation between power dissipation of the microheater and corresponding surface temperature of the gas-sensitive NiO layer. The character shape of the conversion curve depending on power dissipation shows two quasi-linear conversion regions. These regions have different extracted thermal resistance values R_{th} (R_{th} ~ 0.382°C/mW for P_s < 200 mW, and R_{th} ~ 0.218°C/mW for P_s > 200 mW).

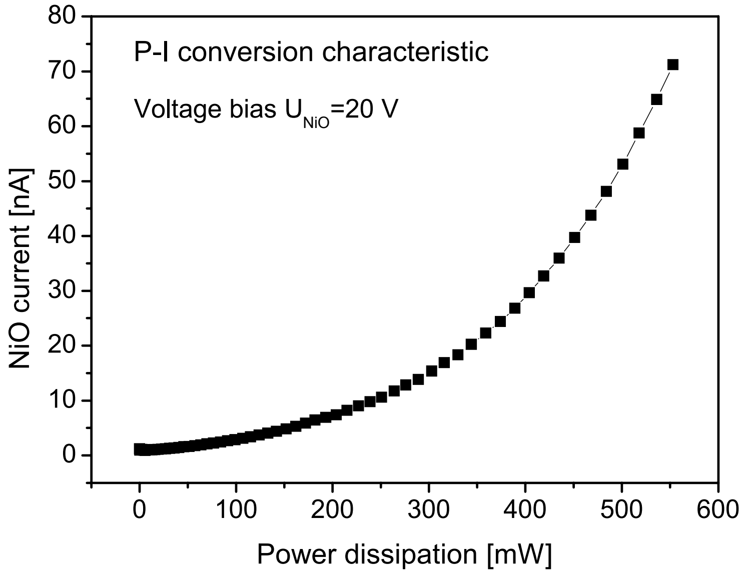

Fig. 10: P-I conversion characteristic of model sensor structure.

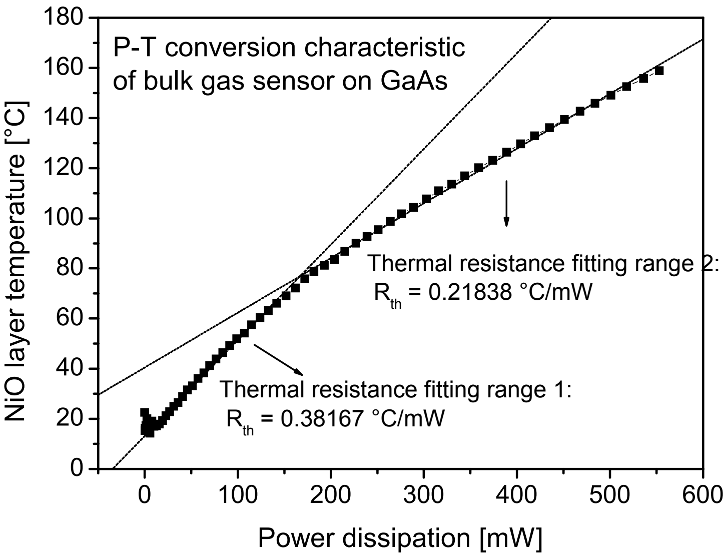

Fig. 11: P-T conversion characteristic of model sensor structure.

CONCLUSION

We presented the fabrication and characterization of a microheater device on GaAs substrate for potential use as a low loss microheated NiO gas sensor. The model sensor structure was subjected to complex electro-thermal characterization to test selected parameters and functional properties of the basic structural elements and materials.

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