Thermal Performance and Stability of Poly Si/Pt(Ni) Thin Film Temperature Sensors on GaAs

Tibor Lalinský* , Pavol Hrkút** , Ž. Mozolová* , Tomáš Kovačik* , and Andrej Krajcer**
*Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská 9, 842 39 Bratislava, Slovakia, eleklali@savba.sk
**Institute of Informatics, Slovak Academy of Sciences, Dúbravská 9, 842 37 Bratislava, Slovakia

SUMMARY

The paper presents the technology, thermal performance and stability of the poly Si/Pt(Ni) thin film temperature sensors on GaAs. Undoped highly-resistive poly Si thin film is designed to be used as a diffusion barrier layer between Pt (or Ni) and GaAs to improve the thermal sensitivity and stability of the temperature sensors. Thermal performance of the temperature sensors at an optimal thickness of the poly Si interfacial barrier layer is evaluated after high-temperature storage tests performed in argon atmosphere at 200 and 250 ^{o}C.

Keywords: Temperature sensors, thin films, thermal stability

INTRODUCTION

Thin metal films are becoming an integral part of microtransducers, and particularly, in thermal-based microsensors where they are designed to serve as low power, high precision, resistive heaters and temperature sensing elements. Here, they are based predominantly on Silicon IC metallization or application-specific special thin film metals [1,2].

Recently, Ni and Pt thin films were designed to be tested as temperature sensing elements on GaAs because of their high temperature coefficients and compatibility with GaAs-based devices and related IC processing steps [3]. In the GaAs device technology, they are mostly involved in metal/GaAs contact systems for alloyed ohmic contact fabrication (AuGe/Ni) and Schottky gate barrier formation (Ti/Pt/Au). Both of the thin films when are deposited directly on GaAs exhibit a high chemical reactivity and interdiffusion effects on GaAs interface mainly at elevated temperatures. This could lead to the degradation of their electrical and thermal properties as was also indicated in [3]. In order to suppress the interfacial interactions, thin diffusion barrier layer has to be formed on GaAs surface before Pt and Ni deposition.

In this paper undoped highly-resistive polysilicon (poly Si) thin film is designed to be tested as a diffusion barrier layer for the Pt and Ni temperature sensors on GaAs. Thermal performance of the poly Si/Pt(Ni) temperature sensors with an optimal thickness of interfacial poly Si barrier layer is evaluated in wide temperature range. High thermal performance and stability are confirmed by preliminary reliability tests performed at 200 and 250 ^{o}C for times up to 300 hours.

DESIGN AND TECHNOLOGY

RF sputtering and electron beam evaporation (EBE) combined with a lift-off technique were used to pattern a meander-like structure of the resistance temperature sensors as shown in Figure 1. Sputtered poly Si barrier layer with various thickness (0, 10, 20, and 30 nm) was immediately followed by EBE of Pt or Ni thin films (Figure 1a). The layer thickness of Pt and Ni was chosen to be 60 nm. The meander-like structure of the temperature sensors was designed with the total length and width of 1300 µm and 3µm, respectively (Fig. 1b).

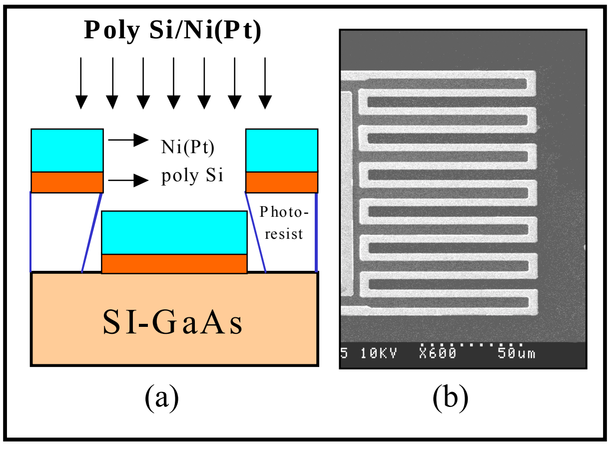

Fig. 1: *Temperature sensors fabrication, (a) thin films deposition and patterning, (b) SEM view of meander-like structure of temperature sensors.*

An optimal thickness of poly Si interfacial barrier layer was evaluated from the measurement of temperature sensitivity of as deposited and annealed Pt/poly Si/GaAs temperature sensors. The sensitivity of temperature sensors with various thickness of poly Si interfacial layer (0, 10, 20, and 30 nm) was measured

after high-temperature annealing at 420 °C for 30 s and compared with as deposited sensor sensitivity.
Figure 2 shows the temperature sensors sensitivity as a function of poly Si thickness. There is a degradation of temperature sensitivity observed in the sensors without any poly Si interfacial barrier layer. This can be explained by an interdiffusion effects on Pt/GaAs interface due to a high chemical reactivity of Pt with GaAs. The sensitivity degradation dominates especially after the high-temperature annealing.

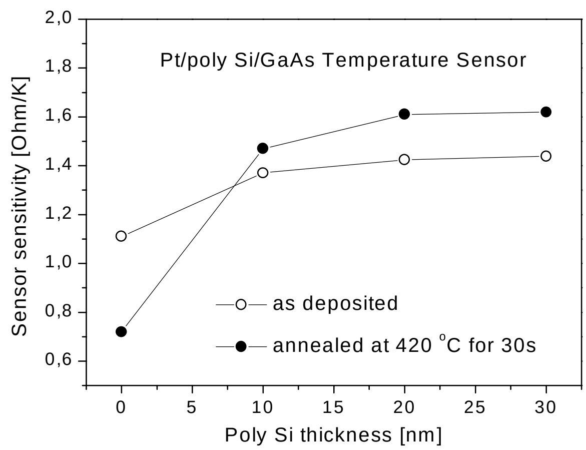

Fig. 2: Temperature sensor sensitivity as a function of poly Si thickness.

It can be seen in Figure 2 that including poly Si interfacial layer, the significant improvements in the temperature sensor sensitivity are observed. Poly Si thickness about 20 nm seems to be sufficient to form a diffusion barrier layer on the GaAs interface.

THERMAL STABILITY AND CHARACTERIZATION

Pt and Ni temperature sensors based on 20 nm-thick poly Si interfacial layer were chosen to be studied in broad temperature range. They are considered to be applied for temperature sensing in a special micromachined power sensor microsystem (PSM) [4,5]. PSM as a GaAs-thermally-based MEMS is designed there to operate at higher temperatures (T=60-150 °C) in order to eliminate the influence of the temperature fluctuation of surrounding atmosphere. The predicted long-time high-temperature operating conditions of the integrated Pt and Ni temperature sensors have led to the study of their thermal stability and reliability.
Reliability tests were performed at 200 and 250 °C for times up to 300 hours in argon protective atmosphere. It is expected that argon protective atmosphere will also be preferable for use for the GaAs-based MEMS device operation. Figures 3, 4 show the sensitivity changes of the temperature sensors after various aging times.

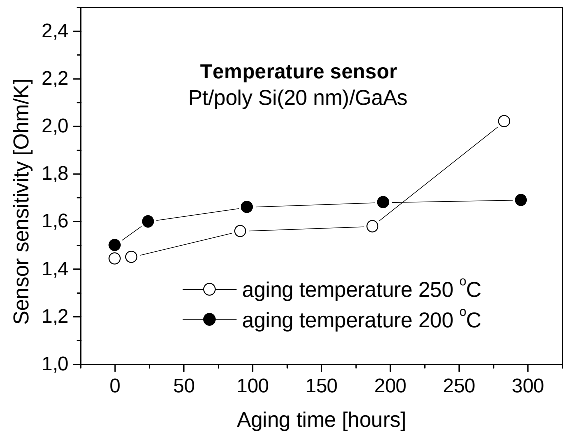

Fig. 3: Long-time aging of Pt temperature sensor

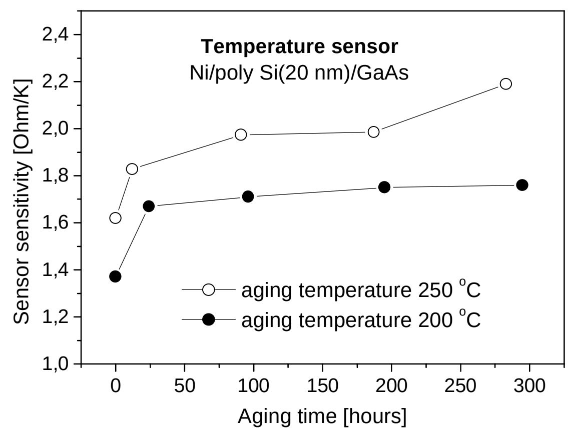

Fig. 4: Long-time aging of Ni temperature sensor

As it can be seen, there is the sensitivity increase indicated in the both types of temperature sensors with the aging time. This is independently observed at both aging temperatures. Even, for aging temperature and time about 250 °C and 300 hours, respectively the sensitivity values higher than 2 Ohm/K are obtained. Hereby, it should be noted that there is no sensitivity degradation indicated after these reliability tests in the argon atmosphere. This can be explained by the diffusion barrier layer of poly Si formed on the both Pt/GaAs and Ni/GaAs interfaces, which prevents to the interdiffusion effects on the interfaces. However, the additional interface microstructure analysis should be performed to confirm it.
Because the temperature sensors are designed to be applied in the temperature range from 300 up to 450 K, the requirement of their temperature stability and reliability seems to be fulfilled.

Next reliability tests at higher aging temperatures are needed to establish the dominant failure mechanisms in the thin film resistance temperature sensors in relation to their temperature sensitivity.

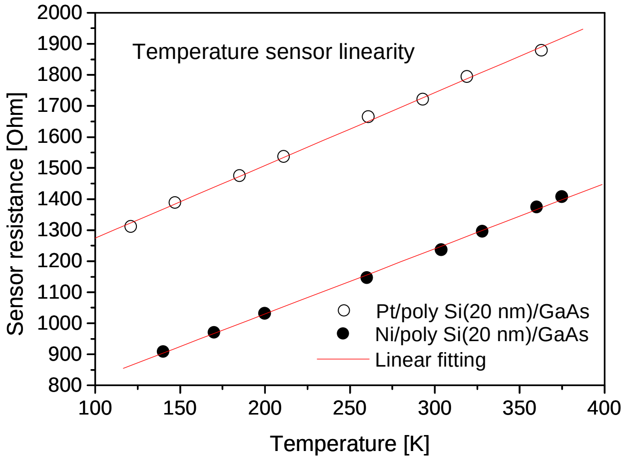

Fig. 5: *Characteristics of Pt and Ni temperature sensors aged at 250 °C for 300 hours in argon atmosphere.*

The temperature linearity of the sensors aged at 250 °C for times up to 300 hours was investigated. Typical characteristics of the sensors are shown in Figure 5. A good temperature sensor linearity and sensitivity (> 2 Ohm/K) can be observed over the broad temperature range investigated (T = 100-400 K).

Because the sensors are predicted to operate in the temperature range from 300 to 450 K, further analysis of the sensors precisely in this operating temperature range was performed. The corresponding characteristics of the sensors are shown in Figure 6.

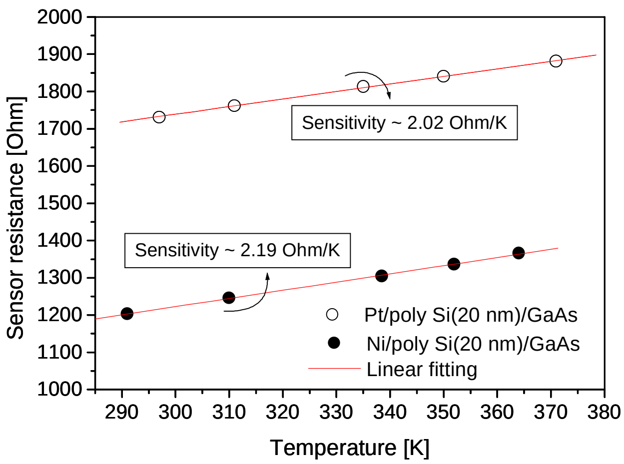

Fig. 6: *Pt and Ni sensor resistance characteristics in operating temperature range.*

They can be fitted very well by a linear function as follows

$$R = R_o + \alpha T$$

where T is the temperature, R_o is the sensor resistance at T= 0 K, and α is the sensor temperature sensitivity. The sensitivity values for Pt and Ni temperature sensors were found to be α_{Pt} = 2.02 Ohm/K and α_{Ni} = 2.19 Ohm/K, respectively.

In the practical applications of the temperature sensors, the sensor voltage at constant current bias is measured with the temperature. Keeping the sensor constant current bias, the sensor voltage as a function of temperature can be obtained as shown in Figure 7. Likewise, there is a very good linearity in the sensor characteristics achieved , which can be used for the temperature sensing.

The sensitivity values extracted at current bias of 0.8 mA were found to be α_{Pt} = 1.5 mV/K and α_{Ni} = 1.67 mV/K for Pt and Ni temperature sensors, respectively.

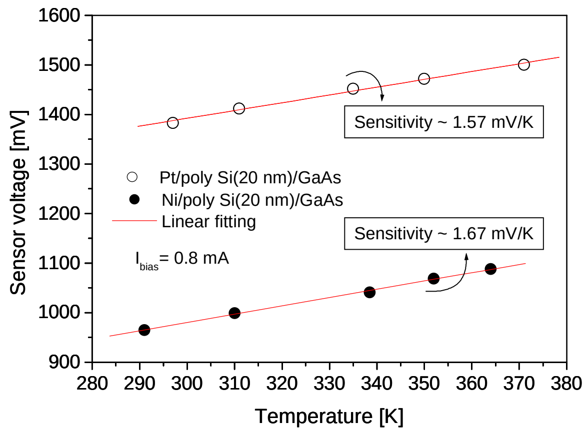

Fig. 7: *Pt and Ni sensor voltage characteristics at current bias of 0.8 mA.*

It should be noted that these sensitivity values depend on the sensor current bias. As a rule they follow the sensor current bias.

CONCLUSION

Platinum (Pt) and Nickel (Ni) thin film temperature sensors on GaAs were investigated. Undoped highly-resistive polysilicon (poly Si) thin film was designed to be tested as a diffusion barrier layer on the both Pt/GaAs and Ni/GaAs interfaces in order to improve the sensor sensitivity and thermal stability.

Pt and Ni temperature sensors with an optimal thickness of the poly Si interfacial layer (~ 20 nm) exhibit high temperature sensitivity ($\alpha_{Pt,Ni}$ > 2 Ohm/K or $\alpha_{Pt,Ni}$ > 1.5 mV/K) and very good linearity after aging storage tests at temperature of 250 °C for 300 hours.

High temperature sensitivity and thermal stability, GaAs IC compatibility as well as very good broad temperature linearity of the thin film resistance temperature sensors developed, make them very attractive for wide range of applications in GaAs-thermally-based MEMS and MOEMS.

ACKNOWLEDGMENTS

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