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NEW TEST STRUCTURE FOR INVESTIGATION OF THE PIEZORESISTIVE EFFECT IN HIGH TEMPERATURE

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Abstract: In different industrial applications, such as injection molding and/or hot rolling, it is necessary to measure pressure in critical environmental conditions where the temperature can reach values in the range of 350-380°C. In these cases, a fluid with low thermal conductivity is now typically used in order to transfer the pressure to the sensitive element, while preserving it from overheats. A preferred solution would be that of obtaining new sensing elements with an intrinsic capability of operation over an extended temperature range. Silicon piezoresistors are unsuitable for use in high-temperature applications due to the significant decrease of the piezoresistive effect in this material with rising temperature. On the other hand, piezoresistive films in SiC has been recently investigated as a material exhibiting a piezoresistive effect, which appears to be exploitable at high temperature [1-3]. The purpose of this work is, therefore, to investigate the possibility of developing a testing structure to evaluate the longitudinal and transverse guage factors (GF_L and GF_T) in piezoresistive films in SiC, to evaluate the TCR and finally to define the temperature effect up to 400°C.

Keywords: SiC, gauge factor, piezoresistors.

1. INTRODUCTION

In different industrial applications, such as injection molding and/or hot rolling, it is necessary to measure pressure in critical environmental conditions where the temperature can reach values higher than 250°C.

In these cases, a fluid with low thermal conductivity is now typically used in order to transfer the pressure to the sensitive element, while preserving it from overheating. A preferred solution would be that of obtaining new sensing elements with an intrinsic capability of operation over an extended temperature range.

Silicon piezoresistors are unsuitable for use in high-temperature applications due to the significant decrease of the piezoresistive effect in this material with rising temperature. On the other hand, piezoresistive films in SiC has been recently investigated as a material exhibiting a piezoresistive effect, which appears to be exploitable at high temperature [1-3]. The purpose of this work is, therefore, to investigate the possibility of developing a testing structure to evaluate the longitudinal and transverse gauge factors (GF_L and GF_T) in piezoresistive films in SiC, to evaluate the TCR and finally to define the temperature effect up to 400°C.

The research goals are the following:

- Design and development of a testing structure with the following characteristic:

input load range (deflection):	0 - 30 µm
bridge resistance:	1 - 5 kΩ
temperature working range:	0 - 400 °C
parameters:	GF_L- GF_T
parameters:	$TCGF_L$- $TCGF_T$
parameters:	TCR

- Design and development of a specific holder suitable for different membranes in SiC;

- Design and development of signal conditioning electronics optimized to operate remotely from both the sensing head and the acquisition unit.

2. TEST STRUCTURE

The sketch of the test apparatus is shown in Fig. 1. A displacement actuator is used to deflect and induce a known amount of strain on the film. To this purpose, a piezoelectric stack was chosen with an internal position feedback provided by a built-in estensimetric sensor. The actuator plunger terminates with a ceramic knife edge that generates a stress on the substrate supporting the piezoresistive film. The stress causes a strain on the film and, in turn, a variation of its resistance which is measured.

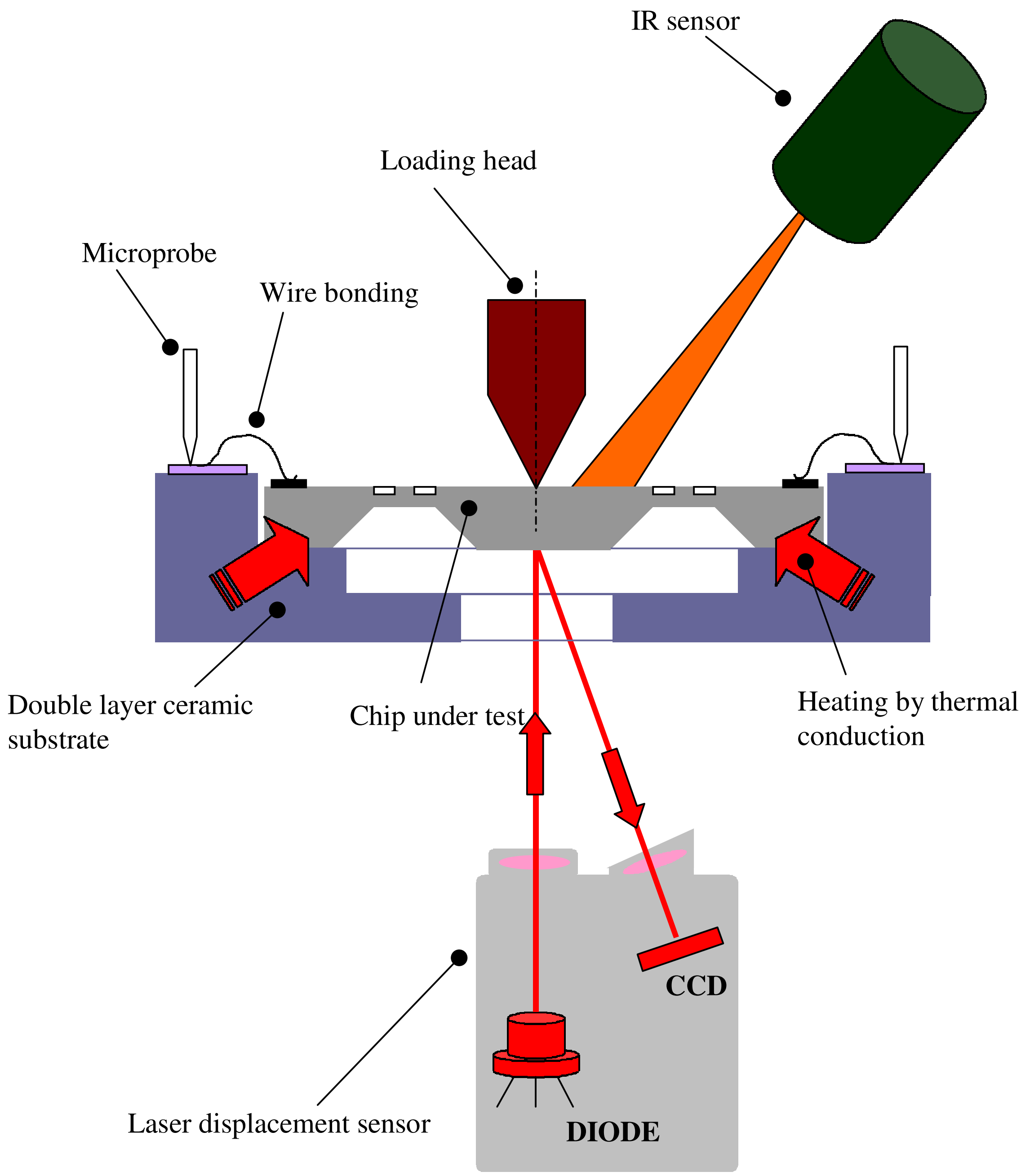


Fig. 1. Sketch of the testing apparatus

The heating of the sample takes place by means of heaters realized in thick-film technology. In Figure 2 photographs of the heating element in thick-film technology on ceramic are reported.

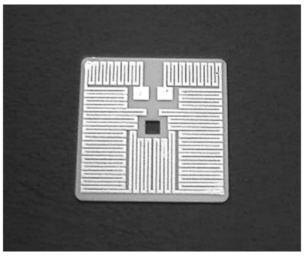
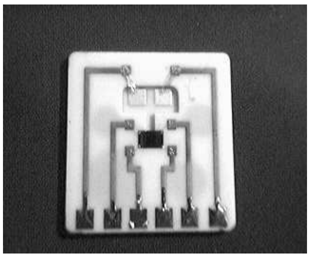
In order to determine accurately the temperature of the substrate under test it is necessary to avoid of directly contacting it, otherwise the measurement could be affected by thermal loading. Therefore, a pyrometer sensor has been adopted.

These temperature measuring sensor mounted into a solid stainless steel housing are designed for precision industrial applications. The measurement accuracy is 0.5 % of reading (spectral range from 8 till to 14 µm).

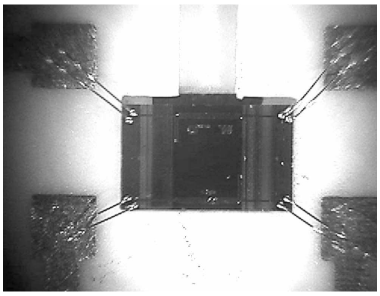
A position sensor to measure the beam deflection has been inserted in the supporting base.

The sensor is a laser optical sensor that uses the optical triangulation principle. The measuring range is 2 mm with a resolution of about 0.1µm. the linearity is of about 0.05 % FSO.

The setting of all the sensors and the sample loading condition is obtained by means of a power amplifier, which communicates with a PC-based data acquisition system. The acquisition system enables to perform automated test cycles and collect data for up to 48 hours.

(a) (b)



(c)

Fig. 2. (a) Photograph of the heating element in thick-film technology on ceramic (b) the full older with the terminations (c) an enlargement of the chip in 3C-SiC with bonding

Concurrently with the experimental characterization of the test structures, the design of the sensor diaphragm is also being optimized with the help of FEM simulations. Fig. 4 shows photograph of the testing structure. In figure 3 is reported an enlargement of the previous photograph with the aim to show the microprobes for the external connection, the loading head and the chip under test.

2. EXPERIMENTAL RESULTS

The fabricated SiC sensors were tested up to 400°C. The slope of the Vout from the chip (Wheatstone bridge output) vs. diaphragm deflection is the sensitivity. A typical value of about 0.35 mV/microns has been found.

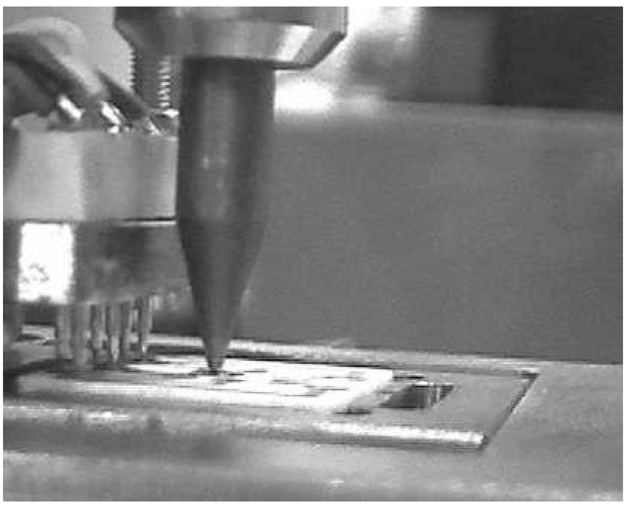


Fig. 3. Photograph of the loading head, microprobes and chip under test

The bridge resistance changes with temperatures up to 350° C are evaluated. The effect of temperature on the resistance is shown in Fig. 3c. It indicates a gradual decrease from room temperature bridge output resistance of 1900 Ω to about 1700 at 300 °C due to increasing ionization of free carriers from SiC epilayer dopants atoms. The upward swing of the bridge resistance of the SiC is associated with the gradual dominance of lattice scattering mechanism over small further increase in carrier concentration with temperature [4].

The gauge factor of the piezoresistors changes with elevating temperature. A value of about 20 has been found. A typical result is reported in Fig. 6. The gauge factor decreases with increasing the temperature up to 350°C. The data (Fig. 5) were consistent with previously reported in literature non-monotonic resistance change with temperature [5]. This poses, for example, a big challenge for temperature compensation of such SiC sensors. A high temperature compensation scheme is currently under development to address this problem. Upon cooling down, the bridge output at zero pressure shifted by 2 mV. While this shift is relatively small, it existence is consistent with the null shifts observed previously. Although the source of the shift is not fully understood, component relaxation during thermal treatment could not be ruled out.

Fig. 4. Photograph of the testing structure

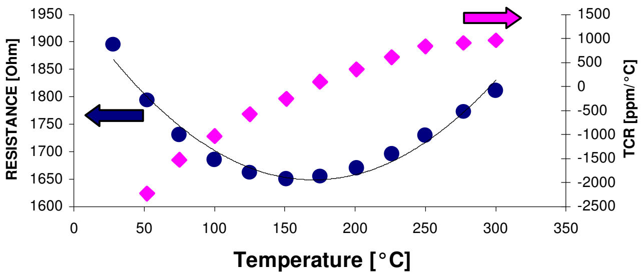


Fig. 5. Bridge Resistance Change With Temperature

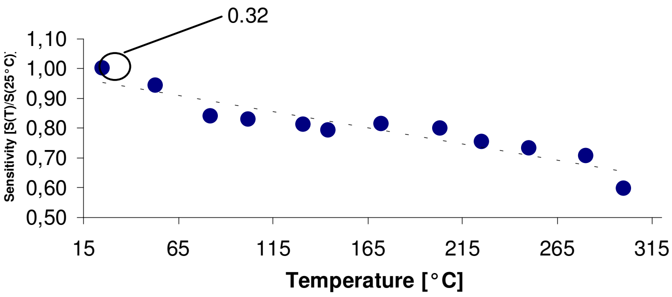


Fig. 6 Sensitivity behaviour of the piezoresistive elements connected in a Wheatstone bridge vs. temperature obtained with the testing structure. The deflection of the diaphragm is 10 microns

3. CONCLUSIONS

The fabricated SiC sensors were tested up to 400°C. The The purpose of this work was to investigate the possibility of developing a testing structure to measure the longitudinal and transverse guage factors (GF_L and GF_T) in piezoresistive films in SiC, to evaluate the TCR and finally to define the temperature effect up to 400°C.

In the following paper a dedicated test structure has been presented together with the preliminary results obtained from piezoresistors realized in SiC technology.

The solution proposed assures the most accurate measurement of the parameters of the film without any undesirable influence. Future improvements will concentrate on the heating process with the aim to test chip up to 500 °C.

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