CHARACTERIZATION OF SOI RESISTORS AS STRAIN GAUGES

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Abstract. *This work describes the fabrication and characterization of Silicon-On-Insulator (SOI) resistors to be used as strain gauges. In order to fabricate the resistors onto SOI wafer, two lithography masks were designed: one to define the SOI resistors and another for Ti/Au electrical contacts that are defined at the extremes of the resistors. Gauge factor measurements were done using the beam-bending method. The SOI resistor was bonded near the clamped edge of a stainless steel cantilever beam and on the free edge were applied calibrated weights. The electrical resistance of the SOI resistor was measured without applied load on the beam and during subsequent tensile loading. The temperature coefficient of resistance (TCR) was also investigated. The results indicate that the SOI resistors have a gauge factor of 22 and a TCR of approximately 140 ppm/ºC.*

Keywords*:Silicon-On-Insulator (SOI), piezoresistive effect, strain gauge, high temperature applications*

1. INTRODUCTION

Semiconductor strain gauges are based on the piezoresistive effect which is defined as the tensor relationship between applied stress and change in resistivity [1]. The main advantage using of this type of device is its greater sensitivity when compared to a metallic strain gauge. Gauge factors for a silicon semiconductor gauge is approximately 130, whereas the typical gauge factor for a metallic equivalent is 2,0 [2,3].

On the other hand, the piezoresistive effect in silicon present a strong temperature dependence. In this context, many studies have been performed on the fabrication of strain gauges in semiconductors materials for high temperature applications as Silicon-On-Insulator (SOI), silicon carbide and DLC (Diamond-like carbon) [1, 4].

In the present work, we report the use of SOI resistors as strain gauges aiming high temperature applications. Silicon-on-Insulator (SOI) wafers consist of three layers: a thin (200 Å to several microns, depending on the application) layer of single-crystal silicon on a thick (1000 to 5000 Å) silicon dioxide layer that is bonded to a conventional "handle" wafer [5]. The first step to developing SOI strain gauges was to design two masks: one to define the SOI resistors and another for electrical contacts. Photolithography techniques were used in conjunction with lift-off processes to fabricate the SOI resistors.

Gauge factor measurements were done using the beam-bending method. The SOI resistor was bonded near the clamped edge of a stainless steel cantilever beam and on the free edge were applied calibrated weights. The electrical resistance of the SOI resistor was measured to each applied load .

The gauge factor (GF) is the measure of the response or strain sensitivity of the resistor and is defined according to equation below:

$$GF = \frac{\Delta R}{R}\frac{1}{\varepsilon} \tag{1}$$

Where R is the nominal electrical resistance, ΔR is the electrical resistance change as a function of the applied load (stress) and ε is the strain.

In the case of the cantilever beam clamped at one end and free at the other, the longitudinal mechanical stress is defined by[6]:

$$\sigma_l = \frac{6FL}{bt^2} \tag{2}$$

Where F is the weight of the block placed on free end of the beam, L, b and t are the lenght, width and thickness of the beam respectively.

The piezoresistive coefficient of the SOI resistor can be obtained from equation (3), that describes the piezoresistive effect [7].

$$\frac{\Delta R}{R} = \pi_{ij}(1-\upsilon)\sigma_l \tag{3}$$

where π_{ij} is the piezoresistive coefficient, υ is the Poisson's coefficient and σ_l is the longitudinal mechanical stress. The temperature coefficient of resistance (TCR) is also an important parameter to evaluate the performance of strain gauges. This coefficient is defined by the equation (4).

$$TCR = \frac{\Delta R}{R}\frac{1}{\Delta T} \tag{4}$$

Where ΔT is the change in temperature.

2. EXPERIMENTAL PROCEDURE

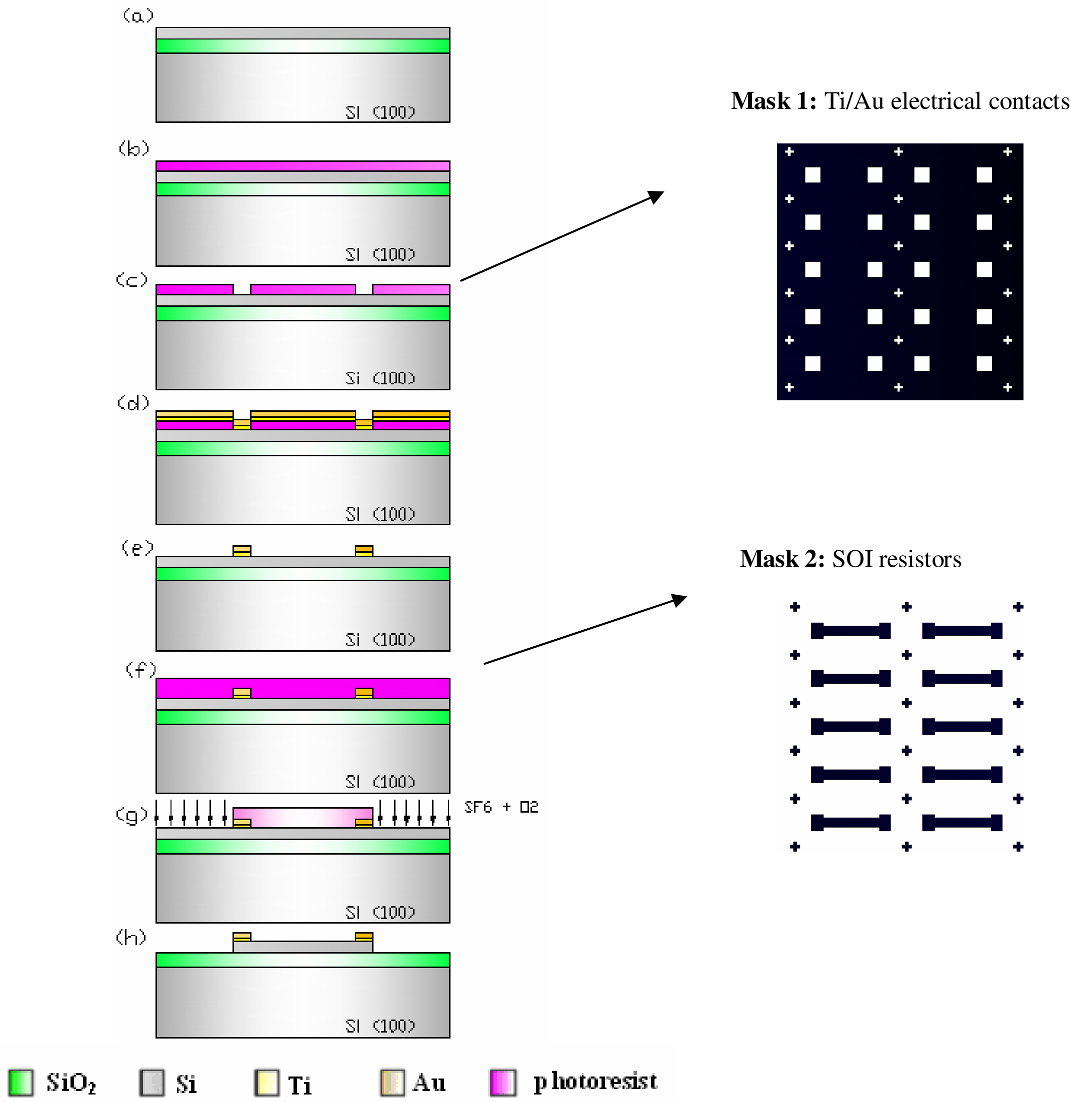

Figure 1. Fabrication steps of the SOI resistors

Photolithography techniques and lift-off processes were used to fabricate the SOI resistors. Fabrication process is schematically shown in Figure 1. The SOI wafer used in this work had a sandwich structure of 0,2 µm thick top Si layer, 0,5µm thick buried oxide (BOX) layer and 250µm Si substrate (see Figure 1 (a)). The wafer surface was coated with a layer of photoresist and the electrical contacts is litographically patterned (Figure 1 (b) and (c)). A layer of 150 nm of Ti was deposited by sputtering over patterned resist. Subsequently, a layer of 250 nm of Au was sputtered onto Ti layer.

The photoresist below metal layer to lift-off metal outside of the pattern of interest was removed using acetone and Ti/Au electrical contacts were obtained (Figure 1 (d) and (e)). A second photolitography was performed to pattern the SOI resistor (Figure 1 (f)). Reactive ion etching (RIE) in SF_6/O_2 gas mixture was used to etch the Si not protected by the photoresist (Figure 1 (g)). Finally, SOI resistor structure was obtained (Figure 1 (h)).

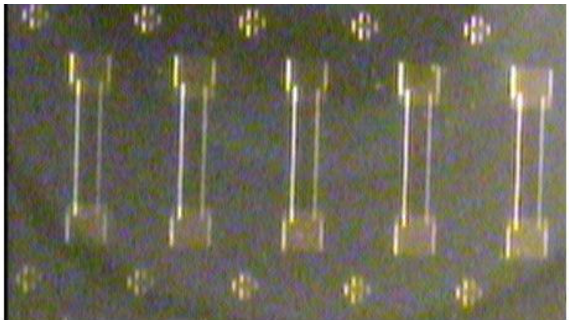

Figure 2. Photograph of the fabricated resistors.

In Figure 2 is shown the photograph of the fabricated resistors. Each resistor is 2,95 mm lenght, 0,6 mm width and 0,01 mm depth and each electrical contact has an area of 1,0 mm^2.

Gauge Factor measurements were done using the beam-bending method. The SOI resistor was bonded with epoxy near clamped end of a stainless steel cantilever beam (120 x 25 x 1,2 mm) and cured at temperature of 120 ºC for 30 min. Calibrated weights (20, 40, 60, 80, 100 g) are applied to the free end of the beam (see Figure 3). The electrical resistance of the SOI resistor was measured to each applied load on the beam.

In order to evaluate the influence of the temperature, the resistance of the SOI resistor was measured incrementally from room temperature up to 250ºC. This experiment allowed to determine the temperature coefficient of resistance (TCR).

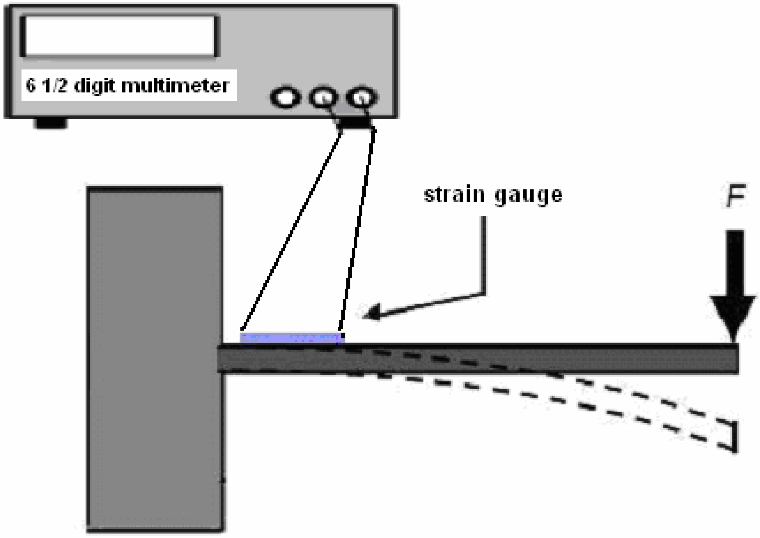

Figure 3. Schematic illustration of the experimental set-up used to characterize the SOI strain gauge.

3. RESULTS AND DISCUSSIONS

The measurements were performed at room temperature and for each applied load the resistance of the SOI resistor was measured 3 times. The change in resistance as a function of the applied force on the beam is presented in Figure 4. The resistance constantly increases as the load is increased. The SOI gauge factor (GF) is given by the slope of the relative change in resistance (ΔR/R) plotted as a function of the strain . As can be observed in Figure 5, The GF of the SOI resistor is 22.

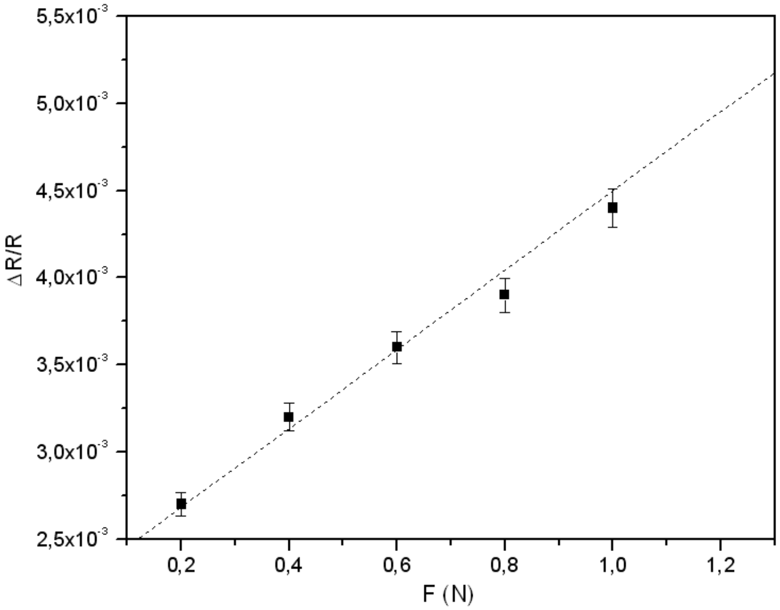

Figure 4. Resistance variation of strained SOI resistor as a function of the applied load on beam at room temperature.

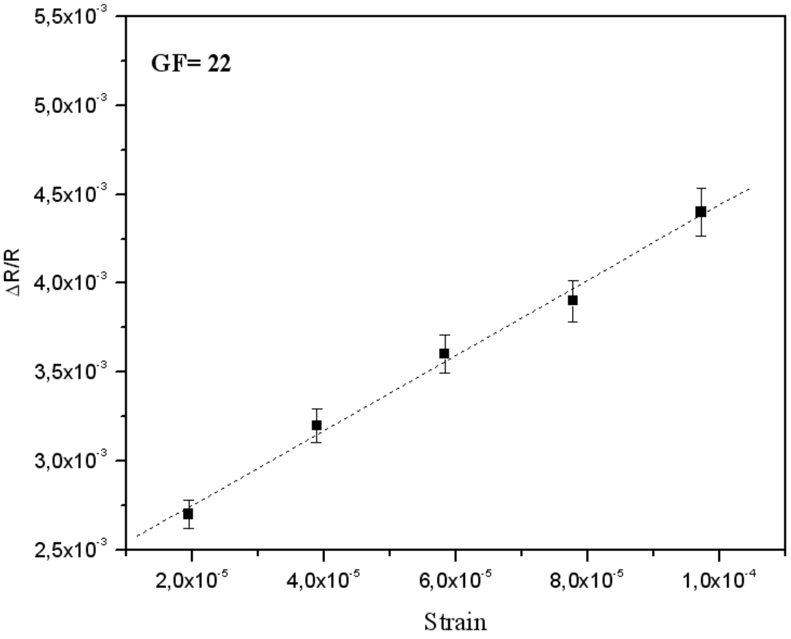

Figure 5. The relative change in resistance (ΔR/R) as a function of the applied strain for the SOI resistor.

In Figure 6, it can be observed that the SOI resistor has a positive temperature coefficient of resistance (TCR) value. This behavior indicates that the electrical resistance of the resistor increases with the temperature. In addition, this resistor exhibits a quasi-constant TCR of approximatelly 140 ppm/ºC between 27ºC and 150ºC. Some studies [8-9] show that piezoresistive materials, for high temperature strain sensors applications, should present preferably TCR positive and constant. This show que the SOI resistors fabricated in this work can be used as strain gauge applications at temperatures up to 150ºC.

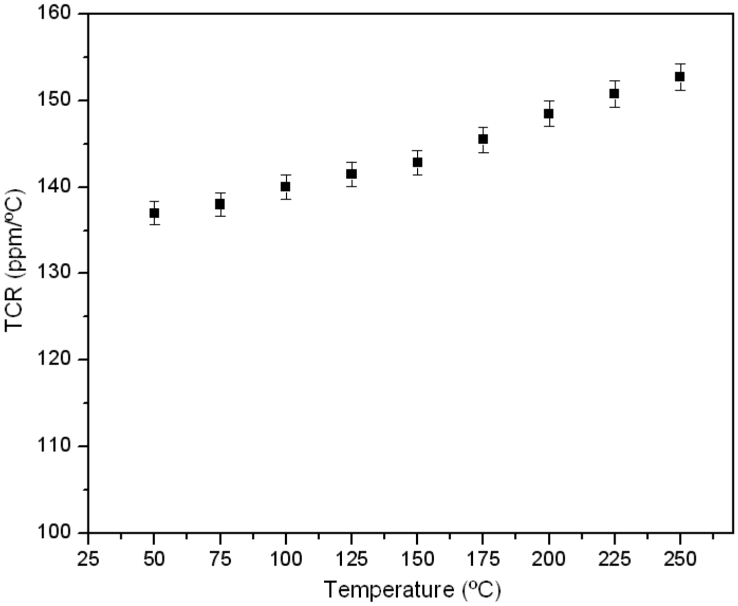

Figure 6. TCR mesurements for SOI resistor.

4. CONCLUSIONS

We have fabricated SOI resistors for strain gauges applications. The experimental results obtained show that the SOI resistors fabricated present a good gauge factor and a quasi-constant temperature coefficient of resistance (TCR) from room temperature up to 150ºC. This shows that in this range of temperature the SOI resistors are appropriate to act as strain gauges.

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