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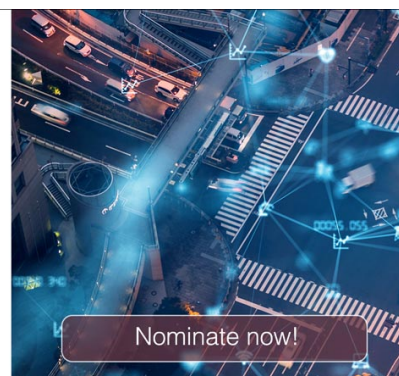


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## Prediction of dynamic behaviour of Pt/SiNx suspended beams for their use in harsh environment

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**Abstract.** This paper reports a mechanical study of double clamped micro beams of an Accelerometerbased on Thermal Convection (ATC). One of the prime application of ATC is shock measurement where the magnitude of acceleration could exceed 20000g [1-2]. The ATC is formed of 3 suspended resistors. The ATC would support a large frequency spectrum of high magnitude due to a shock application. The eigen frequencies has to be found because the resonant effect could destroy the suspended resistors. Analytic results describe the heater resistor as tensile string [4]. Finite element method (FEM) and measurement of resonant frequencies with interferometric microscope validate the tensile string model [5]. Also by experimental measurement, it is shown that the increase of temperature reduces the tensile stress of the beam and then the values of resonance frequencies.

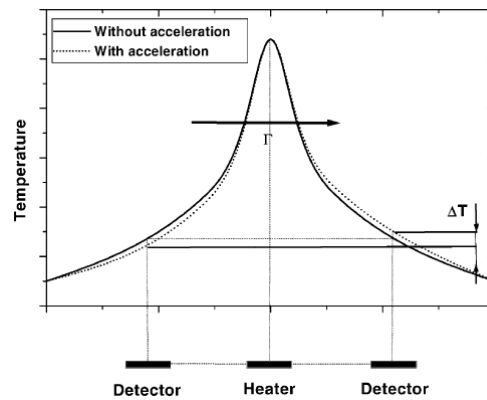
### 1. Introduction

Thermal micro machined accelerometers have been intensively studied because of their high shock reliability. This reliability is due to lack of seismic mass [1-2]. The main application of this kind of accelerometer is high magnitude shock detection in automotive industry like air bag crash detection or defence applications [3]. The goal of this paper is to demonstrate that the behaviour of the suspended resistors is the same as tensile string [5]. This comparison is done by FEM and by experiments with an interferometric microscope. The innovation of this paper consists in the measurements of resonant frequencies by heating the thermal resistors. The final objective is to study the influence of temperature on resonance frequencies.

### 2. Physical principle and microstructure design

The ATC is based on free convection in a sealed chamber containing N<sub>2</sub> [1-3]. As shown in figure 1, The heater resistor is placed between two detectors. When the heating resistor is powered, it creates a symmetrical temperature profile. Consequently, the detectors are at the same temperature (continuous line). Although in presence of acceleration, the thermal gradient tends to shift in the same direction than the acceleration (dotted line). By knowing the coefficient of thermal resistance (CTR) and the resistance at 0 °C (R<sub>0</sub>) of the platinum resistor, the difference of electric voltage collected between the two detection resistors is converted into difference of temperature. The shift in temperature is proportional to the acceleration [2].





**Figure 1:** View of the thermal gradient with the disposition of resistors

The heater resistance temperature could exceed 150 °C, then it's important to study the influence of temperature on resonant frequencies.

### 3. Analytical results and FEM modelisation

The beam is described by a clamped-clamped beam model, with one degree of freedom, given by Euler Bernoulli equation [5-6]. Although in the case of high tensile constrain ( $L \gg h$  where  $L$  the length and  $h$  is the thickness of the heater) the resonance frequencies are a first mode integer multiple. The equation below (1) describes the frequency of the  $n^{\text{th}}$  mode with  $n=1,2,3$  as a function of tensile stress  $\sigma$ , the mass density  $\rho$  and the length of the beam  $L$ :

$$f_n = \frac{n}{2L} \sqrt{\frac{\sigma}{\rho}}, \quad (1)$$

This model is suitable for beams composed by only one material. Although FEM need to be performed in order to determine the resonance frequencies and the mode shape for a SiNx/Pt beam. The FEM is achieved with ANSYS software. Analysis for two different lengths and widths of the beam is performed: the first is 2000  $\mu\text{m}$  by 50  $\mu\text{m}$  and a second is 500  $\mu\text{m}$  by 10  $\mu\text{m}$ . These dimensions correspond to different device design [2]. The thickness of SiNx beams is around 500 nm. SiNx/Pt beams is 500 nm for SiNx layer and 300 nm for Pt layer. The results of FEM are given in Table 1. The results are classified by compositions and dimensions of the beams:

**Table 1 :** FEM results

| Composition | Size( $\mu\text{m}$ ) | f1(kHz) | f2 (kHz) | f3 (kHz) |
|-------------|-----------------------|---------|----------|----------|
| SiNx        | 500*10                | 173     | 348      | 526      |
| SiNx        | 2000*50               | 44      | 89       | 134      |
| SiNx/Pt     | 500*10                | 160     | 322      | 486      |
| SiNx/Pt     | 2000*50               | 33      | 67       | 78       |

However, for FEM it's necessary to know the stress values of SiNx and SiNx/Pt beams. The tensile stress  $\sigma$  is found by using the equation (1). Table 2 shows the tensile stress deduced from the measurement of resonant frequencies at  $T = 23^\circ\text{C}$  with  $\rho_m$  the average volumic mass of the suspended resistor:

**Table 2** : Tensile stress deduced from equation (1)

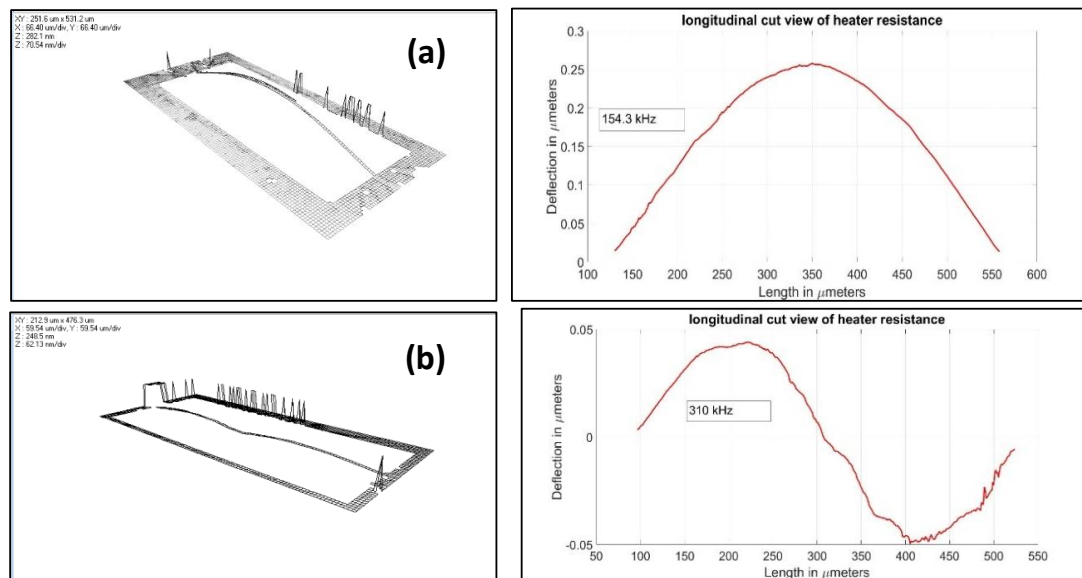
| Composition | Size( $\mu\text{m}$ ) | $\rho_m(\text{gr.cm}^{-3})$ | $\sigma$ (MPa) |
|-------------|-----------------------|-----------------------------|----------------|
| SiNx        | 500*10                | 3,15                        | 100            |
| SiNx        | 2000*50               | 3,15                        | 107            |
| SiNx/Pt     | 500*10                | 10                          | 253            |
| SiNx/Pt     | 2000*50               | 10                          | 192            |

The resonance frequencies are a first mode integer multiple of the first mode and the mode shapes are the same as tensile string. This result is valid for every size and composition of the beam studied. The next part presents the experimental values of eigen frequencies and mode shapes found by an interferometric microscope.

#### 4. The Experimental Data and discussions

##### 4.1 Modes shapes and resonant frequencies

Experimental measurement of frequencies and mode shape is done by the *Fogale photomap 3D*, optical profiling system. This system is combined with an ultrasonic transducer which allows scanning bandwidth in order to find eigen frequencies and mode shapes. The mode shape at the resonant frequencies are found by vibrometry in stroboscopic light [7] and are shown in Figure 2. The measurements have been done on SiNx/Pt resistor of 500  $\mu\text{m}$  by 10  $\mu\text{m}$ . In order to get a clear view of the flexural displacement, the ratio of Y-axis: X-axis, was chosen around 1:5000:



**Figure 2:** Experimental deformed shape of the (a) first, (b) second mode in 3D view and longitudinal cut view

The behaviour of SiNx and SiNx/Pt beam were the same as tensile string. The values in table 3 shows very good agreement between experimental (Table 3) and FEM results (Table 1):

**Table 3:** Measured resonance with optical profilometer

| Composition | Size( $\mu\text{m}$ ) | $f1(\text{KHz})$ | $f2$  | $f3$   |
|-------------|-----------------------|------------------|-------|--------|
| SiNx        | 500*10                | 173              | 349   | /      |
| SiNx        | 2000*50               | 45.80            | 92.02 | 139.4  |
| SiNx/Pt     | 500*10                | 154.06           | 309.6 | 468.3  |
| SiNx/Pt     | 2000*50               | 34.46            | 68.91 | 103.48 |

FEM shows a good prediction of the resonant frequency and the shape of deformation.

#### 4.2 Influence of the temperature on resonant frequencies

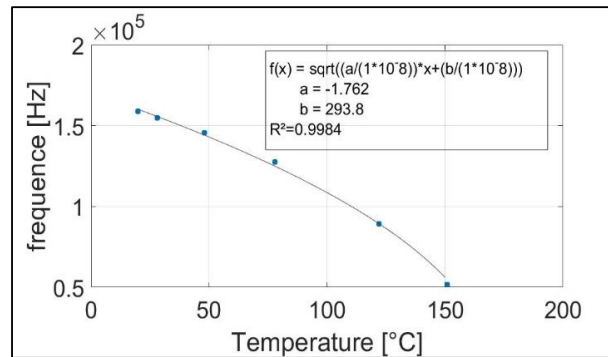
The operating heater resistor temperature was around 200 °C. With a DC generator an electric current through this resistor was set. The knowledge of CTR and Ro allows us deducing temperature as a function of the electric current. The result of SiNx/Pt 500 by 10 µm of beam for five different temperatures are gathered in table 4. The eigen frequency of the first mode and the equivalent tensile stress with equation (1) were calculated:

**Table 4:** Eigen frequencies and tensile stress as a function of temperature

| $T (^{\circ}\text{C})$ | $f_1(\text{kHz})$ | $\sigma (\text{MPa})$ |
|------------------------|-------------------|-----------------------|
| 21                     | 159,2             | 253                   |
| 47                     | 154,9             | 239                   |
| 78                     | 145,9             | 212                   |
| 122                    | 89,3              | 80                    |
| 151                    | 51,8              | 27                    |

The increase in temperature shifts the resonant frequency to lower frequencies. Unfortunately, it is difficult to measure the resonant frequency at a temperature higher than 150 °C, because of mechanical bulking of the beam [5]. In figure 3,  $f(T)=f$  with equation (2) is fitted, with the young modulus  $E$  [MPa], and  $\alpha$  the thermal expansion [ $\text{K}^{-1}$ ]:

$$f_n = \frac{n}{2L} \sqrt{\frac{\sigma_0 + E \times \alpha \times (T - T_0)}{\rho}}, \quad (2)$$



**Figure 3:** resonant frequencies vs Temperature and its square root regression (2)

Experiment and theoretical model are well matched. By extrapolation for a sample of SiNx/Pt beam of 500 by 10 µm at 200 °C, the resonance frequency is 18,500 kHz.

#### 5. Conclusion

FEM and experiments allows us to conclude that Euler Bernoulli model in the case of high tensile stress is suitable to describe suspended resistor of ATC. By experimental measurements, the result of 500 by 10 µm beams out of plane resonant frequency is around 154 kHz at ambient temperature. Nevertheless, the increase of temperature reduces the value of resonant frequency by reducing the value of tensile stress. The next step of our work is to find a link between the amplitude of acceleration and the deflection of the suspended resistor. In order to estimate the critical acceleration before damaging the device, a combined experimental-analytical approach is possible by measuring the quality factor and

resonant frequency [10]. Finally, FEM approach could be carried out to determine the maximum acceleration in function of the frequency.

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