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ELECTRONIC SYSTEM FOR THE DETECTION OF VOLATILE ORGANIC VAPORS

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Abstract: This work shows the application of piezoelectric PZT in the detection of vapors of volatile organic compounds, such as alcohols. The model of a resonator system was applied to obtain the mechanical behavior, particularly the amplitude of the resonance frequency. An electrical circuit was implemented to measure the impedance value of the trampoline, which is manifested as the minimum voltage in the voltage divider circuit that corresponds to the resonance frequency of the trampoline. For the detection of organic vapors, a film of ethyl cellulose was deposited on the piezoelectric using the casting method. A change in its resonance frequency is proportional to the increase in mass. The resonance frequency of the trampoline was 4.751 KHz, with a shift of 30 Hz produced by the deposition of the sensitive film, and its response to ethanol was a frequency shift of 79 Hz.

Keywords: Organic vapors, resonance frequency, mechanical vibrations.

INTRODUCTION

Detecting gases when there are hundreds of different gases and which are also found in different proportions, is a difficult and complicated task, since each application must have unique requirements. What is true is that most sensors are not specific for a certain gas but are sensitive to a group or family of gases [1]. In recent years, technological evolution has created a growing demand for all types of sensors and actuators that allow automatic interaction of machines with their environment or with human existence. The study of sensors and actuators for the monitoring and diagnosis of diseases, such as cancer, diabetes, genetic diseases, among others, has created the need to control a large number of biological and chemical substances, in order to have more in-depth studies, which They would surely improve the present tests, this could represent hope for many sick people [2]. The field of sensors is large, including those that react to physical properties such as temperature, pressure, radiation or those that detect biological molecules such as biosensors [3]. A biosensor is an analytical system composed of an immobilized biological material, in intimate contact with a suitable transducer that converts the biochemical signal into a quantifiable electrical signal [4, 5]. Sensors based on trampoline-type structures are the ideal transducer for chemical and biological sensors; they can be used for molecular recognition, gas detection, etc. Its operation is based on the transduction that produces the magnitude to be measured, in a mechanical action of the trampoline. Its principle of dynamic behavior allows detecting changes in the resonance frequency due to the presence of molecules of some substance [6, 7]. Trampoline-based sensors have their origin and main thrust in the SPM (Scannning Probe Microscope) and AFM (atomic force microscopes). These microscopes base their operation on detecting the interaction between a surface and the tip of the microscope, suspended from a springboard [8]. Electrochemical resonators such as flexible plates, quartz crystal microbalances and surface acoustic waves have applications as sensitive mass transducers, which are useful as chemical and biological sensors. Previous studies had already demonstrated the possibility of measuring optical and chemical stimuli, gases in the environment and liquids, with standard and modified microtrampolines. More recently, with an ultra-thin silicon resonator (20 to 50 nm), magnetic forces of the order of 4x10-20 J/T and optical forces of approximately: 10^{-17} N [9].

METHODOLOGY

In resonant trampoline-type structures, the resonance frequency of the system depends on the elasticity constant and Poisson's ratio of the material, the thickness and length of the free plate of the trampoline. In this section, a piezoelectric trampoline is analyzed and characterized by applying the model of a resonator system in order to obtain the mechanical behavior. Particularly the frequency-dependent displacement amplitude. This in order to measure mass in chemical or biological applications. Timoshenko's cantilever analysis presents a great approximation [10-11]. However, it is very difficult to find a model that considers all the material and its characteristics.

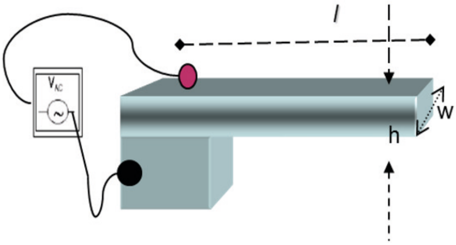

Figure 1: Trampoline-type resonant structures.

The empirical relationship was determined by an American society for testing and materials; based on the work of 'Goen's and Pickett's' [12]. For a diving board or cantilever, the resonance frequency can be calculated according to equation (1).

$$f_{res} = 0.1604 \cdot \sqrt{\frac{E \cdot \left(1-v^2\right)}{\rho}} \cdot \left(\frac{h}{l^2}\right) \qquad (1)$$

where:

E = elasticity constant of trampoline material (Si)

v = Poisson's ratio of the material

ρ = material density

h = trampoline thickness

l = trampoline free lever length

In the case of static sensors, it causes a continuous deflection of the trampoline. For chemical sensors or biosensors, a selective polymer is placed on some type of substance that, when the molecules adhere, produce a change in mass and/or a stress on the surface that causes the static deflection of the trampoline [13-14]. According to Hook's Law, the deflection (y) at the free end experienced by the trampoline results as expressed in equation (2).

$$y = \frac{4F.l^3}{E.w.h^3} \qquad (2)$$

where F is the force applied at the free end and w is the width.

The main applications of trampolines are based on the previous expressions, as mass sensors, when experiencing changes in the resonance frequency, as an accelerometer or mechanical vibration sensor due to the changes between displacement and acceleration when stimulated with a mechanical vibration, and it is also used as a force or displacement sensor due to its elasticity, among others.

As the trampoline increases its mass, a change in its resonance frequency Δf appears. It is possible to demonstrate that the increase in mass is proportional to the frequency shift by a constant, as expressed in equation (3).

$$\Delta m = 0.0261E(1-v^2)\frac{wh^3}{l^3}\left(\frac{\Delta f}{f_0^3}\right) \qquad (3)$$

Measuring mass through frequency changes is a good measurement method, without noise effects and high resolution; Defining a few Hertz in the measurement results in a resolution on the order of nanograms.

To find the resonance impedance of the trampoline, a voltage divider was implemented with the trampoline as the Z impedance, as shown in Figure 2.

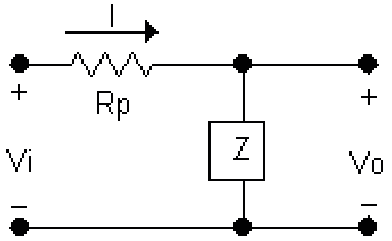

Figure 2: Voltage divider with springboard as Z impedance.

The impedance Z can be calculated in terms of *Vi, Vo and Rp*. Where Rp is the proposed resistance, equation (4).

$$Z = \frac{VoRp}{Vi - Vo} \qquad (4)$$

To find the resonant frequency of the trampolines, a frequency sweep is performed through a data acquisition system with the DAQ data acquisition card and the impedance of the circuit is calculated. The system used consists of a commercial data acquisition card, the National Instrument (NI) PCI-6036E, and a computer with a sound card. The MatLab program is used to execute the designed programs and functions.

RESULTS

At the resonance frequency, the impedance value of the trampoline is minimum, that is, it presents little resistance to move, therefore, the potential difference in the voltage divider circuit manifests itself as the minimum voltage on the trampoline. Figure 3 shows the approximation of the resonance frequency of the PZT trampoline, with a length of 6.53 e-3m, thickness of 0.62 e-3m, elastic constant of 8.3 e10 N/m2, and Poissón's Ratio (v) of 0.32. A sweep was performed from 2.5 to 7.0 KHz, with increments of 30 Hz, the resonance frequency shown is 4.762 KHz, with an accuracy of ±30 Hz.

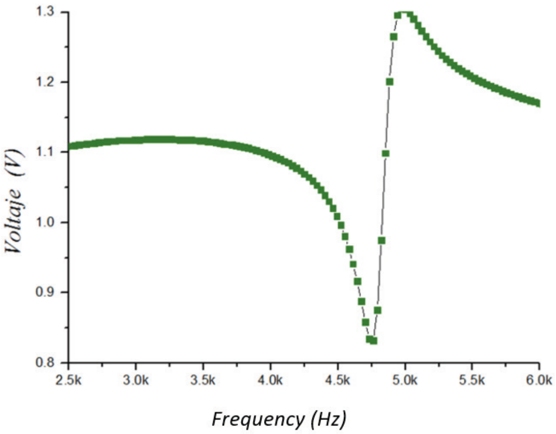

Figure 3: Frequency sweep for PZT piezoelectric trampoline from 2.5 KHz to 6 KHz.

To deposit the sensitive film, the casting method was used, which is the simplest of all and simply consists of depositing the solution through a syringe. After evaporation of the solvent, the sensitive film is obtained. For our work, a sensitive film was deposited using 10 mg of ethyl cellulose, dissolved in 10 µl of chloroform, a micropipette was used to control the amount of film that was placed on the free end of the trampoline, as shown in Figure 4.

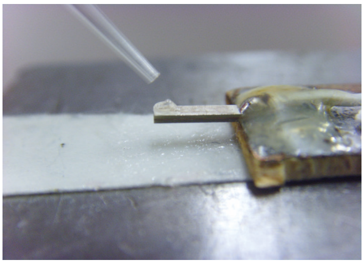

Figure 4: Casting method for depositing the sensitive film on a springboard.

The response of the sensor to the presence of ethanol is measured by placing it inside a Teflon chamber into which a maximum of 200 µl of ethanol can be injected. The Teflon chamber is immersed inside a scientific thermos (NESLAB RTE-10) that maintains a finished temperature with a stability of +/- 0.01°C, Figure 5.

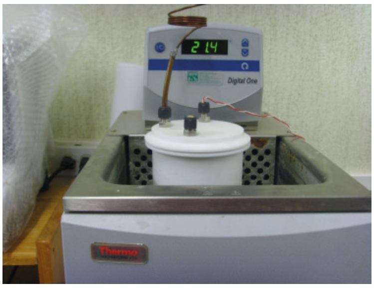

Figure 5: The Teflon chamber is immersed inside a scientific thermos (NESLAB RTE-10).

Figure 6 shows the response of the sensor in the presence of ethanol. A frequency sweep was performed in a range of 4.5 to 5.1 kHz, with intervals of 10 Hz. Taking the frequency variation with and without film as a reference. The resonant frequency of the trampoline is 4.751 kHz without film. In this graph you can see the variation of the resonance frequency, when injecting samples of 50 µl of ethanol, every 15 min. The resonance frequency changes as the amount of ethanol increases.

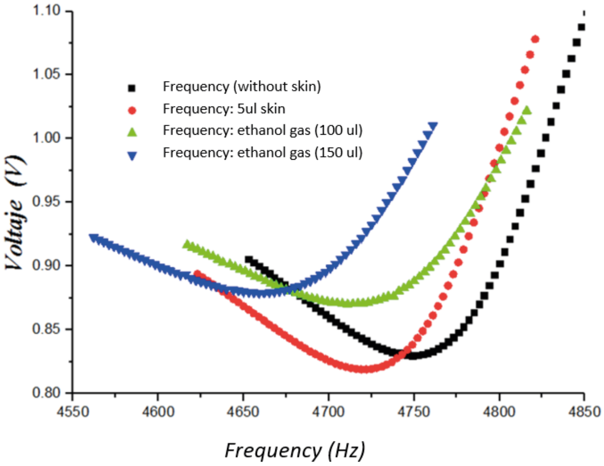

Figure 6: Variation of the resonance frequency with film and when detecting the presence of gas molecules (ethanol).

Finally, the springboard resonance frequency of 4.751 kHz was obtained, with a shift of 30 Hz produced by the deposition of the sensitive ethyl cellulose film and the resonance frequency is 4.642 kHz. Its response to ethanol was a frequency shift of 79 Hz, with a concentration of 56.058 ppm.

CONCLUSIONS

For this work, a piezoelectric ceramic trampoline was analyzed and characterized and the model of a resonator system was applied to obtain the mechanical behavior, particularly the displacement amplitude dependent on the resonance frequency in order to measure mass. For the detection of volatile organic vapors, a sensitive film of ethyl cellulose was applied to the free end of the piezoelectric springboard using the casting method and its response was measured by introducing it into a Teflon chamber into which a maximum of 150 µl of ethanol was injected. The Teflon chamber is immersed in a thermal bath (NESLAB RTE-10) to maintain stable temperature with an accuracy of +/-0.01°C. The results have been used to determine the weight of an adsorbed material through a decrease in resonance frequency.

The resonance frequency of the trampoline was obtained at 4.751 KHz, without film, and the resonance frequency with a 5 µl film was 4.721 KHz, causing a shift of 30 Hz. Finally, the response of the sensor in the presence of ethanol was obtained., its frequency with gas is 4.642 KHz, causing a frequency shift of 79 Hz. With a concentration of 56.058 ppm.

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