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Title: Design and simulation of a piezoelectric transducer by finite element

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Introduction

In the electronics industry, the manufacture of electronic devices depends on the characteristics of the materials and their design.Currently for the design of microsensors and microactuators using integrated circuit technology or microelectromechanical systems (MEMS), it is necessary to know the behavior of the materials used since their properties are critical in the performance and operation of manufactured devices (H. Baltes, et al, 2002).

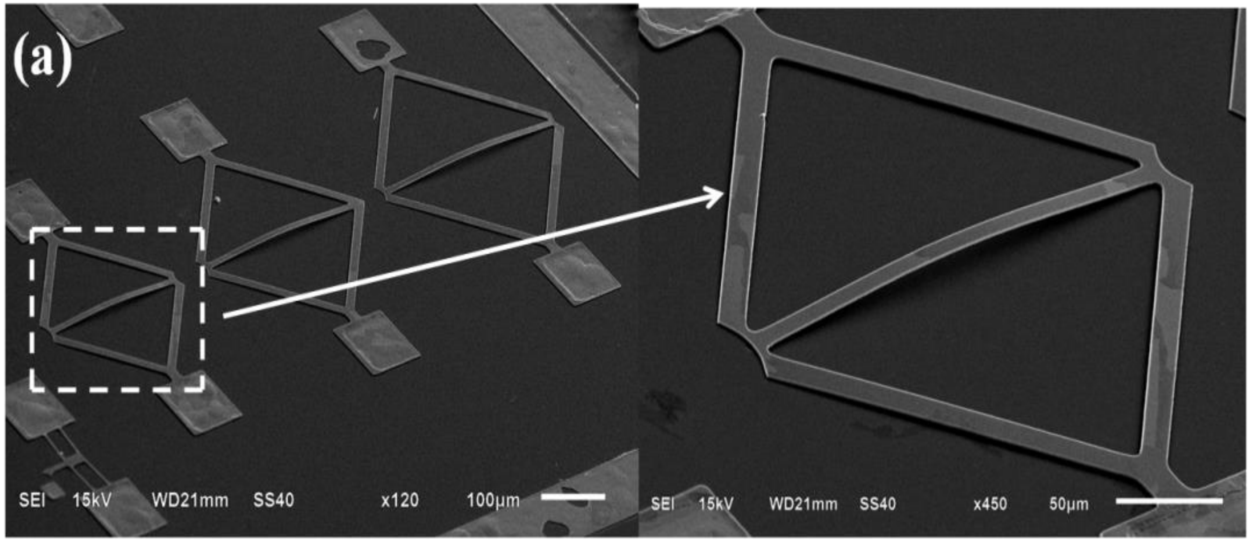


Figura 5.5: Microestructuras tipo diamante, (a) a-SiB:H, (b) a-$Si_{0.5}Ge_{0.5}$B:H.

Young's modulus is a physical property, which quantifies the elasticity that a material has when it is subjected to a mechanical deformation caused by an external force. For characterizing mechanics of the materials there are different techniques, which require special equipment and also expensive. For example the technique by mechanical indentation instrumented (J.M. Meza, et al. 2008), the technique by Stress-Strain (Kuo-Shen Chen) and the Resonance Frequency Tracking Technique (Perez Ruiz S.J et al. 2008). Most characterization techniques require samples with certain characteristic.

In this work a finite element analysis is performed in cantilever-type structures to determine Young's modulus in silicon-germanium amorphous films (a- SiGe).

Methodology

The resonance frequency occurs when the vibration periods of the applied force and the material coincide. The amplitude is maximum in its resonant state. The resonant frequency of a cantilever-type structure depends on its geometric dimensions, its density and its Young's modulus, based on the Euler-Bernuilli model (Singiresu S. Rao) and is expressed as Equation 1 (S. Alcantara et, al. 2010).

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

Where E is the Young's modulus of the material, ν the Poisson's ratio, the volumetric density ρ ($\rho = m / l.h.w$), the thickness h, w the width of the plate and l the length of the plate.

By depositing a thin film of on the surface of the cantilever structure, it causes an increase in its mass Δm, which generates a change in the resonant frequency $(\Delta F_{res=} f_0'^2 - f_0^2)$. From equation 1, we can determine the amount of mass deposited on the cantilever. The increase of mass is expressed by equation 2.

$$\boldsymbol{\Delta m = 0.0261.E.\left(1 - v^2\right)\frac{W.h^3}{l^3}\left[\frac{1}{f_0'^2} - \frac{1}{f_0^2}\right] \quad 2}$$

Young's modulus (E) of the material can be solved from equation 2, being expressed with the equation 3.

$$\boldsymbol{E = \frac{\Delta m}{0.0261.\left(1 - v^2\right)} \cdot \frac{l^3}{W.h^3}\left(f_0'^2 - f_0^2\right) \qquad 3}$$

Where f_0 is the resonant frequency of the cantilever and f_0' belongs to the frequency of the cantilever with the thin film.

In this work we will analyze the simulation of the dynamic behavior of amorphous Silicon-Germanium (a-SiGe) thin films, on a cantilever-type piezoelectric structure. To perform the simulations using the finite element method (FEM), the ANSYS® Multiphysics software was used (Gockenbach, S. M. 2006).

This tool is very versatile for the simulation of microstructures; its analysis allows us to obtain an approximate numerical solution on the behaviour. To carry out the simulations, it is necessary to know the material properties: electrical, mechanical and thermal.

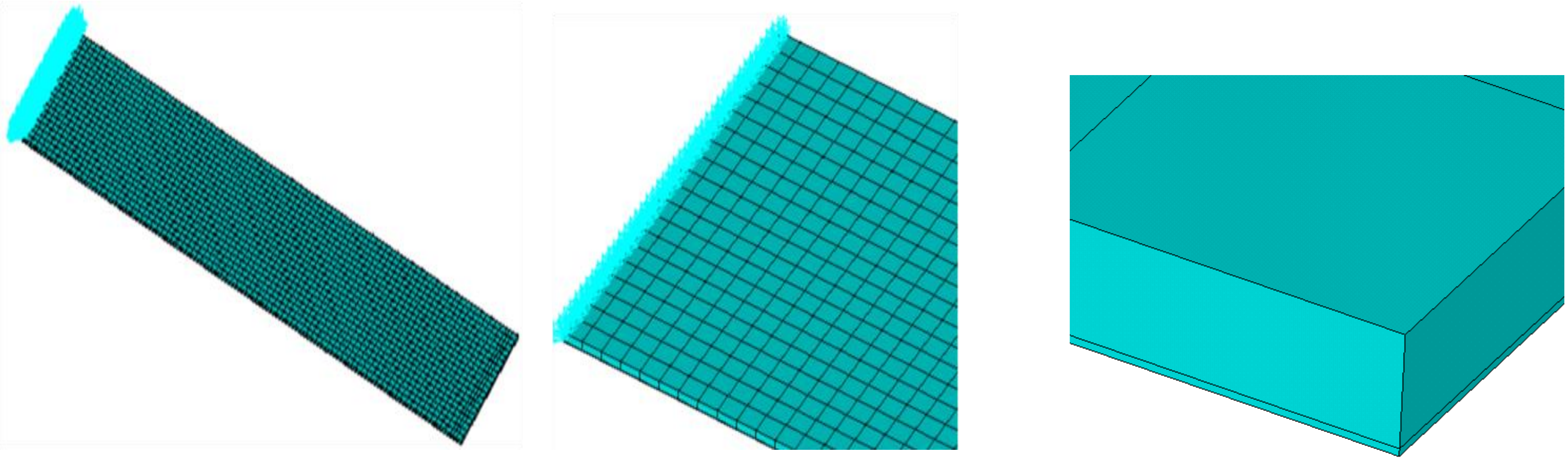
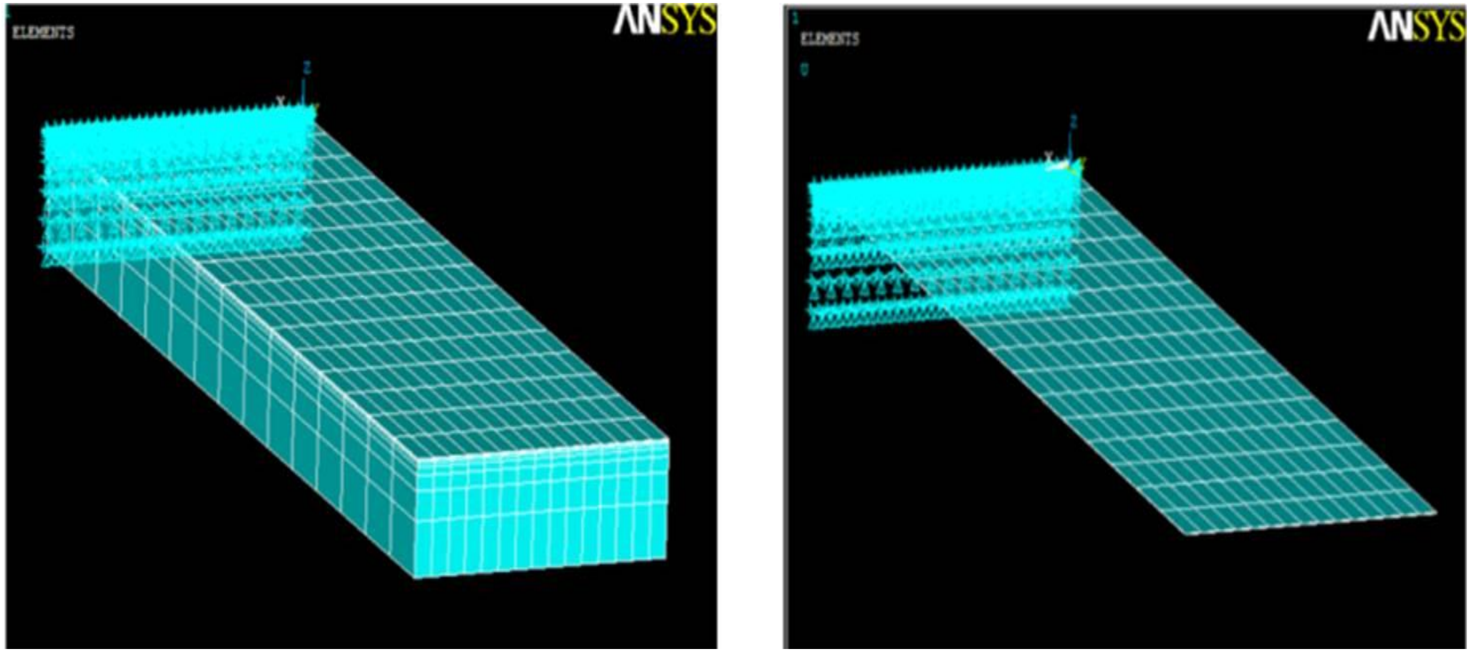


Figure 1. Cantilever meshing whit Solid98 elements.

Results

For the simulations, it is considered that the cantilever is embedded at one end, that it does not move in any direction, they have a length l= 5.8mm, a width w=1.54mm, thickness h= 0.55mm, its Young's Modulus is $E = 83\ GPa$, Poisson's ratio $v = 0.32$ and a volumetric density $\rho = 7700$ Kg/m^3.



a) **b)**

Figure 2. a) Piezoelectric Cantilever (PZT), b) thin film of amorphous material.

The simulation results for the piezoelectric trampoline show its first vibration mode located at 11922.3 Hz, figure 3.

Mechanical propeties	a-Si:H	a-Ge:H
Coefficient of expansion	2.33x10^{-6} K^{-1}	5,75x10^{-6} K^{-1}
Density	2330 kg/m^3	5323 kg/m^3
Young´s Module (GPa)	150	110
Poisson´s ratio	0.28	0.25
Thermal conductivity	148W/(K.m)	59,9W/(K.m)
Stress σ (MPa)	50T-500C	800T-800C
Compressive Stress (Pa)	3.667e^9	5.982e^8
Tensile Stress (Pa)	509832	3.233e^7
Energy Gap Eg (eV)	1.8	0.78
Reflection index (n)	3.4	4

Table 1. Mechanical properties of amorphous materials (J. Lee, C-J. Kim,2000).

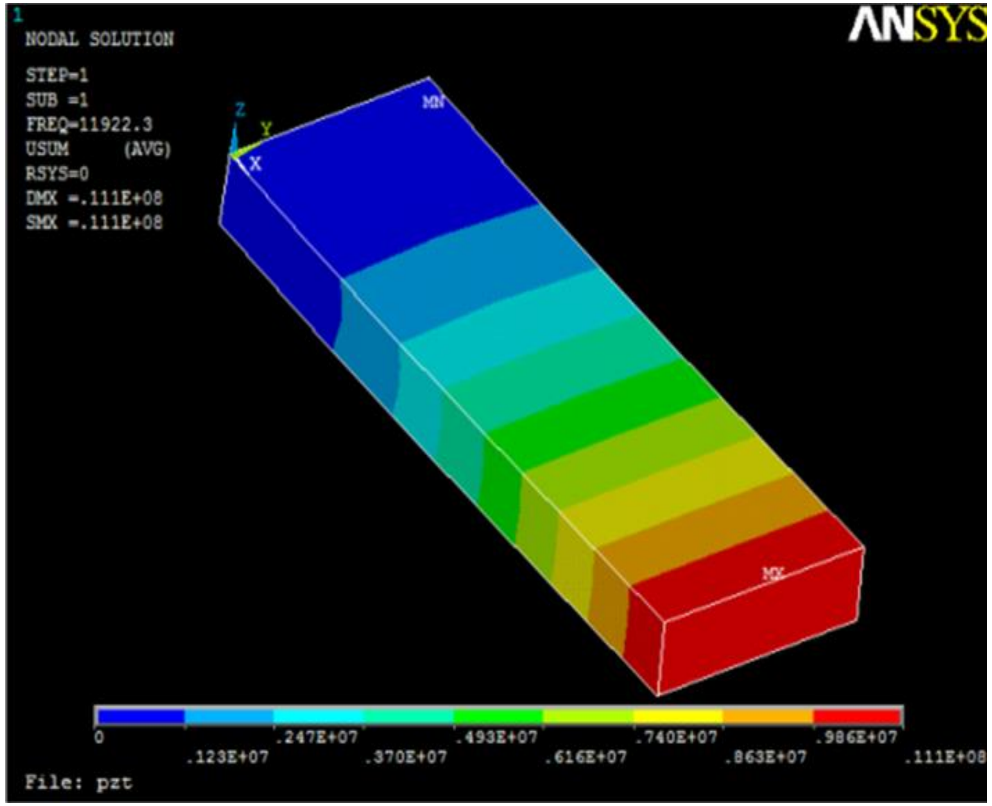
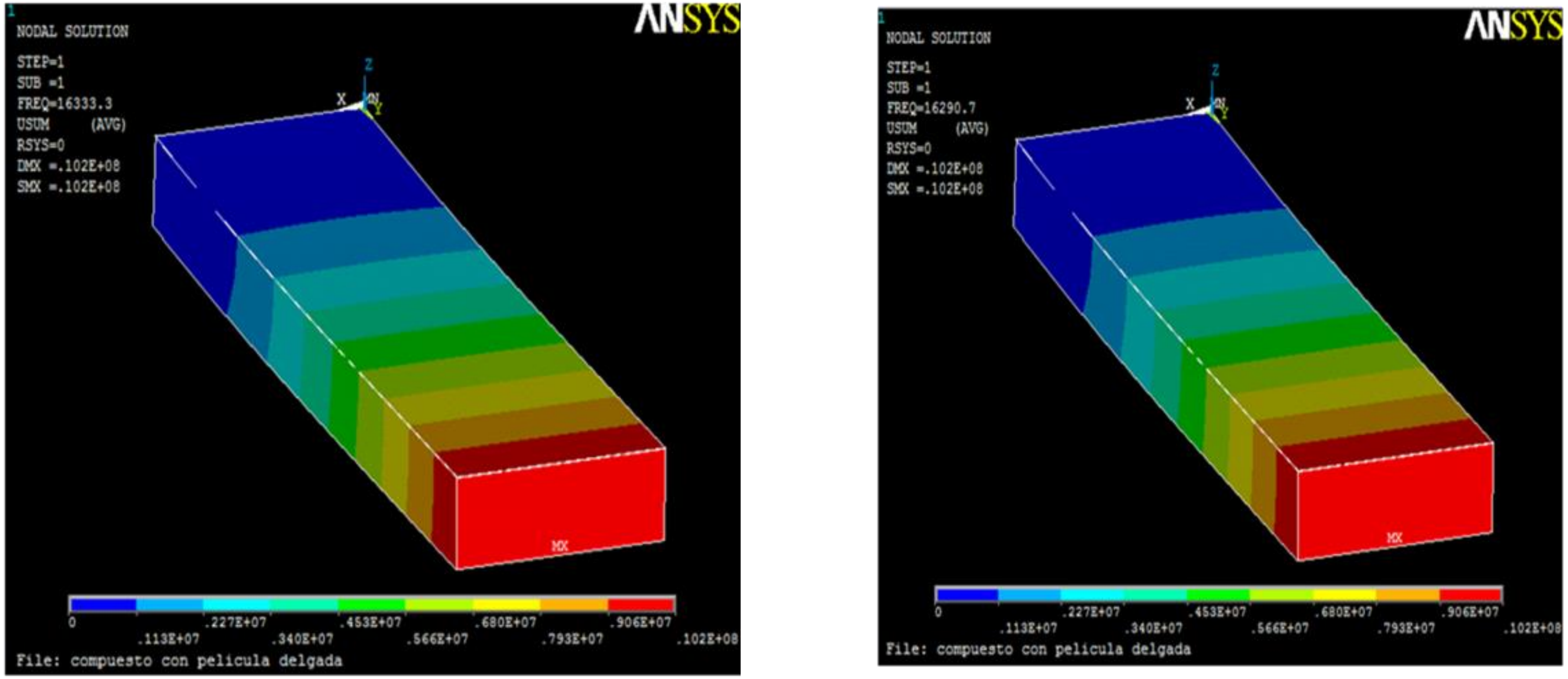


Figure 3. Piezoelectric Cantilever (PZT) resonance frequency 11922.3 Hz

The results are shown in figure 5. For an Amorphous Silicon-germanium film with a concentration of 75% and 25% (a-$Si_{75\%}Ge_{25\%}$), a Frequency of 16333.3Hz was obtained. Figure 5 b) shows a resonance frequency of 16290.7 Hz for a thin film of the Amorphous Silicon-germanium alloy with a concentration of 50% and 50% (a-$Si_{50\%}Ge_{50\%}$).



a) **b)**

Figure 5. a) For a-$Si_{75\%}Ge_{25\%}$ film a resonance Frequency of 16333.3Hz was obtained, b) shows a resonance frequency of 16290.7 Hz for a thin film of a-$Si_{50\%}Ge_{50\%}$.

The calculated resonance frequency of the PZT cantilever with amorphous a-SiGe films, using the finite element method (FEM) in the ANSYS® software, is shown in table 2. Young's Modulus of the a-SiGe films is calculated using equation 3, where f_0 is the resonance frequency of the piezoelectric cantilever and f_0' belongs to the frequency of the piezoelectric cantilever PZT with the films of the Silicon-Germanium material amorphous (a-SiGe).

Material	Frequency (KHz)	Young's Modulus (GPa)
PZT	8.7	8.3
PZT(a-Si:H)	16.38	150
PZT(a-$Si_{75\%}Ge_{25\%}$:H)	16.33	140
PZT(a-$Si_{50\%}Ge_{50\%}$:H)	16.29	130
PZT(a-$Si_{25\%}Ge_{75\%}$:H)	16.24	120
PZT(a-Ge:H)	16.17	110

Table 2. Resonance frequency behaviour of cantilever PZT whit thin a-SiGe films.

Conclusions

The results obtained by simulation in ANSYS, shows an indirect way to measure the Young's modulus of thin films. If the properties of the materials are known, it is possible to have a more precise analysis of the mechanical behavior of the structures. For this work, the mechanical properties of amorphous silicon and germanium were considered. The results obtained from the simulation in ANSYS show a linear behavior of the Young's Modulus when varying the germanium content in the thin films of amorphous Silicon.

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