THERMAL DEFORMATION EFFECT ON VIBRATION OF NANO-COMPOSITE BEAM

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1 Introduction

Nanoelectromechanical systems(NEMS) have been studied with interest increasing recently as growing commercial applications. Because NEMS devices have ultra-sensitive detection, the devices can be used at the part of a nanorobot, a signal importation, and so on[1]. The frequency of NEMS devices can shift from MHz to GHz regime by changing the dimension.

A magnetomotive transduction technique was used to excite the resonators and measure their response[2]. But it is not easy to measure the response experimentally. Therefore, it will be useful to predict a mechanical behavior of NEMS by computer simulation because of reducing of the experimental cost and time.

This paper focuses on analyzing the thermal residual stress of composite nanomechanical resonators made of ultra thin(30 nm thick) SiC and 30~225 nm of aluminum by using MSC.NASTRAN. Moreover, we tried computing simulation to find how the residual stress affects the frequency of the nanocomposite beam.

2 Manufacturing process of nanocomposite beam

Ultra-thin single-crystal 3C-SiC films were grown on a silicon wafer by a heteroepitaxial atmospheric pressure chemical vapour(APCVD) process. The epitaxial process is a two-step, high-temperature(1280℃) procedure, involving the carbonization of the Si surface in a C_3H_8/H_2 ambient followed by epitaxial growth using SiH_4, C_3H_8 and H_2. The films used in this study were 30nm thick. The nano-scale resonators were fabricated using electron-beam (E-beam) lithography combined with reactive ion etching. E-beam lithography, followed by evaporation and lift-off of aluminum, is used to define the device pattern on top of the SiC surface. After a total of 2 min of etching, this recipe first clears the silicon carbide film not covered by aluminum, and then etches into the silicon substrate isotropically, thereby releasing the doubly clamped beam device structure. The complete long beam is shown figure 1.

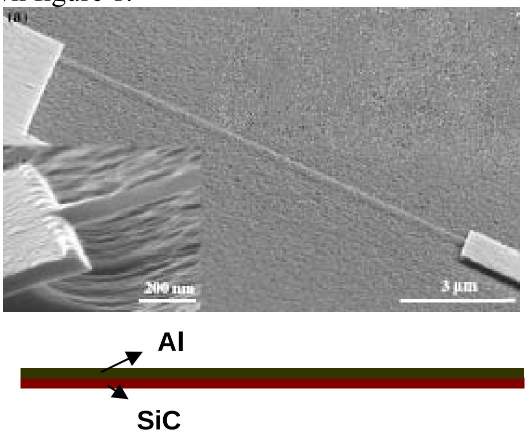

Fig.1. Al-SiC nanocomposite beam

3 Effects of thermal stress on frequency

3.1 A simplified model

We first consider a beam composed of a single material, and then generalize the results to the case of a composite beam of SiC and Al.

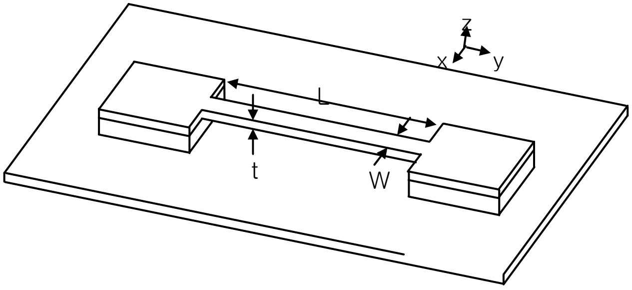

Fig 3. Doublely-clamped beam with length L, width

w and thickness t. The end supports are assumed infinitely rigid[5].

The natural frequency for the simplified beam model is

$$f_0 = 1.03\frac{w}{\ell^2}\sqrt{\frac{E_e}{\rho_e}} \qquad (1)$$

where l is the length of the beam, ρ is the density, E is the Young's modulus, w is the beam width in plane of vibration.

For the composite beam, we can apply the effective Young's modulus E_e and the effective density ρ_e to Equation 1. The parameters are

$$E_e = \frac{E_{SiC}A_{SiC} + E_{Al}A_{Al}}{A_{SiC} + A_{Al}} \qquad (2)$$

$$\rho_e = \frac{\rho_{SiC}A_{SiC} + \rho_{Al}A_{Al}}{A_{SiC} + A_{Al}} \qquad (3)$$

where A_{SiC} and A_{Al} are the area of Al and SiC[6].

3.2 3D FEM model

Actually, it's difficult to predict the mechnical behavior by the simplified formulas as equation 1~3 because there is residual stress in the nanocomposite beam caused the difference of the thermal expansion coefficient between almuminum and siclicon carbide. Therefore, 3D FEM analysis is required to simulate the complicated mechanical behavior exactly.

The model of the nanocomposite beam is composed by two materials SiC and Al. These material's properties are as table1.

Material	SiC	Al
Young's Modulus(Gpa)	410	68
Density(kg m-3)	3200	2700
Thermal expansion coefficient(K^{-1})	$4*10^{-6}$	$2.4*10^{-5}$
Poisson ratio	0.14	0.33

Table1. The material properties of SiC and Al used to model the nanocomposite beam[7-9].

We modeled four cases. The beam's length is 3µm, and the SiC layer of lower floor has a constant thickness to 30nm at four cases. The Al layer which is upper part of the nanocomposite beam changes to 30nm, 65nm, 115nm, and 165nm at each case.

For modeling, we used Msc. Patran. The ends of the models are fixed to x, y, and z directions because the model is a double clamped beam whose length remains fixed. At first, we use linear static alalysis option for getting the residual stress happened at the manufacturing processor. The temperature change from 660℃ to 20℃ because the aluminum' s melting point is 660℃ and the room temperature is 20℃. At the next analysis, we get the frequency of the nanocmoposite beam with the residual stress by using normal mode analysis option.

4. The results of analysis

Figure 1 is to draw the frequencies of nanocomposite beams. In these cases, the thickness of aluminum layer is changed from 30nm to 195nm, and we try to compute the temperature of the beam increase by DC heating power. The first graph is the results of simulation at each aluminum layer. We can know the frequency of nanocomposite beam decrease as the thickness of aluminum layer increase from the first graph of figure1. The next graph is to compute the frequency when the temperature of beam is changed. As the temperature of the beams increase, the frequency of the beam decrease as figure 1.

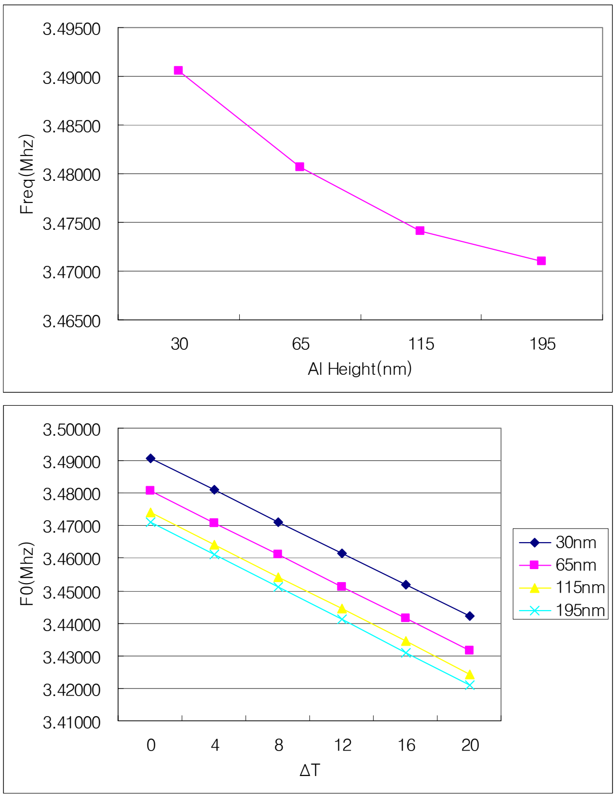

Figure 1. The frequency of nanocomposite beam.

6 Conclusions

- This paper focuses on analyzing the effect of residual stress on vibration of nanocomposite beam by simulation 3D FEM model using MSC.

Nastran. As a result of this study, we know that the frequency tuning ability can be modified by varying the aluminum layer thickness, and The difference of thermal expansion between silicon carbide and aluminum increases the frequency of beam.

7 References

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