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Suitability of Single Walled Boron Nitride Nanotubes as a Glucose Detector

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Abstract

The feasibility of the Boron Nitride Nanotubes (BNNTs) as nanomechanical resonators is investigated in the present study. An FEM model of fixed-free SWBNNT is used to investigate the suitability of SWBNNT as glucose sensor.Dynamic analysis of fixed free SWBNNT has been carried out with different dimension of nanotubes keeping thickness and diameter constant.In this paper we have calculated the frequency shift of SWBNNT by taking difference of resonant frequency of SWBNNT with and without the glucose atom. It is investigated that more is a frequency shift more will be the mass sensitivity of nanotubes.

1. Introduction

The discovery of CNT in 1991, gave scientist a new platform for research in this field [1].Studies have proved that CNT contains the excellent electrical, thermal and mechanical properties [4-8] By doing further investigation CNT was classified into two namely Single Walled Carbon Nanotubes(SWCNT) and Multi Walled Carbon Nanotubes (MWCNT).MWCNT was considered to be more complex in terms of properties in comparison to SWCNT [9].CNT has a wide applicaton in various areas[10-14].It can be used as a Field Effect Transistor biosensors[12].So,it gave a new way to researchers to explore something new. Moving forward to this Blase et al predicted of Boron Nitride Nanotubes [15] from the hexagonal boron nitride.Researchers discovered the relationship between hexagonal Boron Nitride and the graphite [18] on the basis of the various properties[16-17].Experiment have proved that BN are semiconducting and have band gap of 5.5ev [19].

Rolling up the hexagonal Boron Nitride in different direction shows different properties [21-25] structural stability[26-27], high mechanical strength [28-33], piezo-electrical properties [35].Due to stability of BNT it can be used as a bio sensor [34] Ciofani et. al suggested that it can be used in nano medicine field. BNT was synthesized by plasma arc method [36]. During production of Boron Nitride Nanotubes environment of helium gas was maintained at 650 torr and current to 50-60 ampere. Dai et. al [25] gave conclusion that mass detection using non-linear oscillation based on continuum elastic model and discussed effect of the mechanical tension on mass detection in harmonic and non-linear oscillations. Mass sensitivity of Boron Nitride Nano Tubes can be known by attaching a mass on tip of the Boron Nitride Nanotubes. It can be done by taking SWBNT in bridged or in the cantilever position and thus by studying the shift in resonant frequency we can know the mass sensitivity of the BNT.

2. Vibration Analysis of SWBNNT Based Nanomechanical Resonator

In this we will use continuum approach inspiring from the continuum model of Carbon Nanotubes used in beam and shell configuration [37-39].Now we will relate analytical equation to resonant frequency of the SWBNNT which is generated by the mass attached on the SWBNNT with the help of the Euler Bernoulli beam theory [40] which is expressed by the equation

$$EI\frac{\partial^2 y}{\partial x^2}+\rho A\frac{\partial^2 y}{\partial t^2}=0 \qquad \text{................(1)}$$

Where A is the cross sectional area E is the Young's Modulus, I is the second moment of cross section and ρ is the density of the material.The resonant frequency of combined system can be derived by considering the length of BNNT as L and the location of attached mass.
The equation of resonant frequency can be given as

$$f = \frac{1}{2\pi}\sqrt{\frac{k_{eq}}{m_{eq}}} \qquad \text{……………..(2)}$$

Where m_{eq} shows the attached mass and the k_{eq} shows the equivalent stiffness. In the present study fixed-free (cantilevered) boundary condition is taken in in consideration. In fixed free boundary, the mass is attached at the tip of free end.

3. Cantilevered SWBNNT with Attached Mass at the Tip

In this we will attach the glucose particle at the tip of the SWBNNT ,which will be considered as mass M, which will give rise to the virtual force at the location of masses that deflection under the mass becomes unity.
Equivalent stiffness deflection shape along the length can be given as

$$k_{eq} = \frac{3EI}{L^3} \qquad \text{……………(3)}$$

and the mass equivalent of SWBNNT can be given as the:

$$m_{eq} = \frac{33}{140}\rho AL + M \qquad \text{……………(4)}$$

4 .Mass_and Resonant Frequency Relationship of BNNT-Based Nanomechanical Resonators

Resonant frequency of SWBNNT depends upon its length, size and diameter. So we will carry out the characterization process to know the length ,diameter etc. of the SWBNNT. If we attach the glucose particle(considered as additional mass),then the resonant frequency of the SWBNNT will change. So by using this concept we will attach glucose particles at different lengths of the SWBNNT (10nm ,8nm, 6nm) by considering the boron nitride tube as the cantilever beam. Frequency depends upon the mass, so by using this concept we have designed a model for mass detection based resonators. Due to attachment of glucose particle there will be shift in resonant frequency. So by calculating the difference in resonant frequency (mass attached and with no mass attached) we can give this model.

$$f_{0_n} = \frac{1}{2\pi}\alpha^2\beta \qquad \text{……………(5)}$$

f_{0_n} represents the resonant frequency of SWBNNT without the without glucose atom and f_n represents the resonant frequency with the glucose atom.

And resonant frequency shift $\triangle f$ due to attached glucose particle can be given as:

$$\triangle f = f_{0_n} - f_n \qquad \text{…………(6)}$$

5. Result And Discussions

In the finite element model, three dimensional model of SWBNNT is designed to calculate the frequency shift. Properties which have been taken in consideration are, elastic modulus of SWBNNT as 1.22 Tpa [11], Poisson's ratio as 0 .35 and the mass density used is 2180kg/m3 [32].Dynamic analysis of fixed-free single walled boron nitrate nanotube has been carried out with the variation in dimensions. Different length of nanotube shows different results having constant diameter.

Table 1-3 shows the first five mode of frequency analysis of single walled boron nitrate nanotube. It is evident from the fig 2 that there is a measurable change in frequency shift .It is clear from the fig 2 that as the length of SWNNT decreases ,frequency shift increases.

The results of SWBNNT as a cantilevered model show that the sensitivity is found more at smaller length. From the analysis result we can conclude that frequency shift is more at 6nm than at 10nm.So the sensitivity of SWBNNT is more at 6nm than the 10 nm.

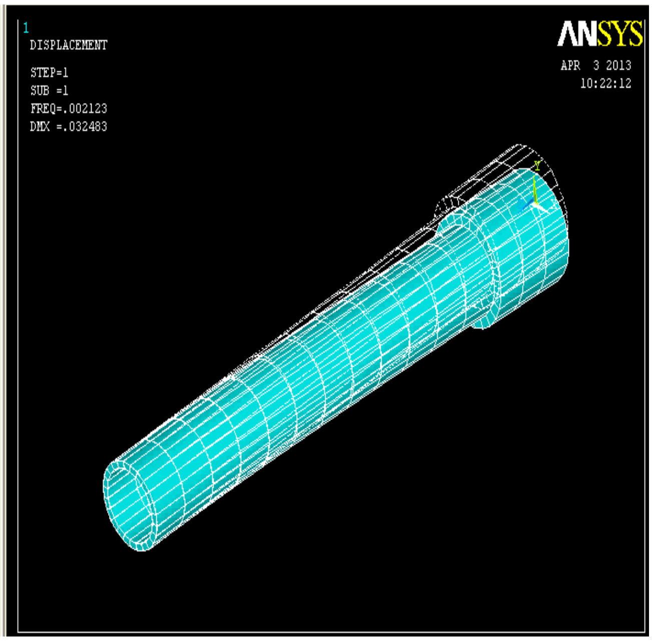


Fig.ISingle walled nitride nanotubes (SWBNNT),3D FEM model with attached glucose particle.

Table I.Resonant Frequency of SWBNNT having length L=6nm

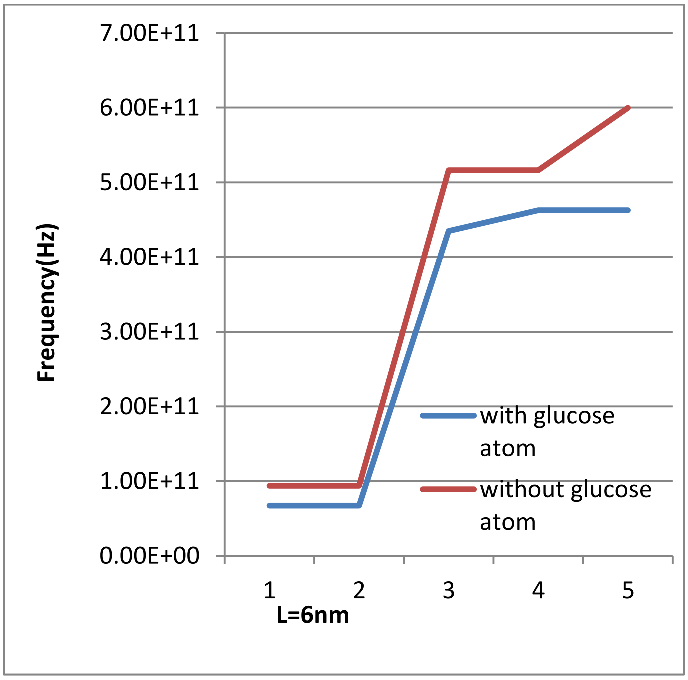
No. of mode	Frequency (with glucose atom)	Frequency (without glucose atom)	Frequency shift (%)
1st mode	0.67129E+11	0.93588E+11	28.27
2nd mode	0.67129E+11	0.93588E+11	28.27
3rd mode	0.43474E+12	0.51609E+12	15.76
4th mode	0.46251E+12	0.51609E+12	10.38
5th mode	0.46251E+12	0.59989E+12	22.90

Table II.Resonant frequency of SWBNNT having length L=8nm

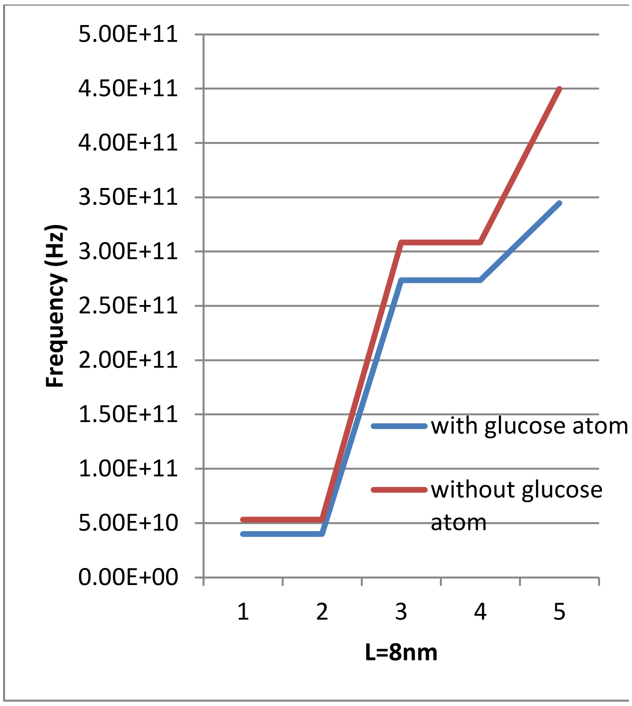
No. of Mode	Frequency (with glucose atom)	Frequency (without glucose atom)	Frequency shift (%)
1st mode	0.39975E+11	0.53171E+11	24.81
2nd mode	0.39984E+11	0.53171E+11	24.80
3rd mode	0.27350E+12	0.30837E+12	11.30
4th mode	0.27359E+12	0.30837E+12	11.27
5th mode	0.34470E+12	0.44991E+12	23.38

Table III:Resonant Frequency of SWBNNT having length L=10nm

No. of Mode	Frequency (with glucose atom)	Frequency (without glucose atom)	Frequency shift (%)
1st mode	0.26690E+11	0.34201E+11	21.96
2nd mode	0.26695E+11	0.34202E+11	21.94
3rd mode	0.18089E+12	0.20357E+12	11.41
4th mode	0.18109E+12	0.20358E+12	11.04
5th mode	0.28739E+12	0.35991E+12	20.14



(a)



(b)

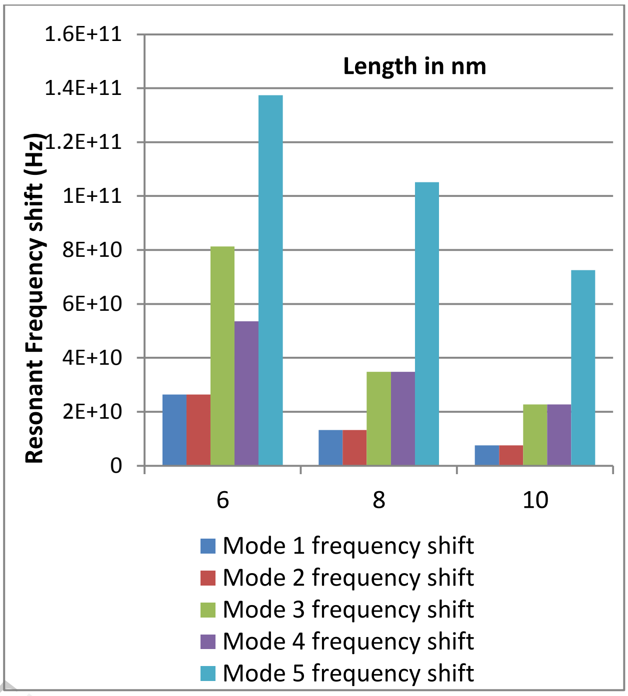
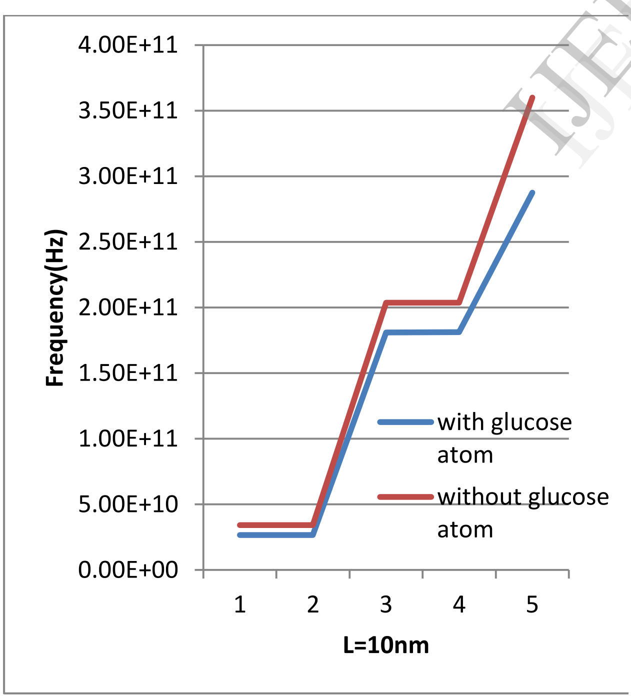


Fig 3.Variations in resonant frequency shift $\triangle f$ to attached glucose particle.



(c)

Fig. 2. Resonant frequency variations to attached mass for SWBNNT nanomechanical resonators of different lengths: (a)L=6 nm (b)L=8nm (c)L=10nm.

6.Conclusion

With the help of results it can be concluded that the manufacturing of such chip is possible which is helpful in detection of diabetic.When the diabetic person exhales then the glucose particle also comes out with co_2 from the nostril.This glucose particle stick on the SWBNNT and due to this resonant frequency changes.The SWBNNT can be used as a nanomechanical resonator cantilever beam.This is done by using continuum approach and doing the FEM analysis of the SWBNNT.The mass sensitivity in terms of change in resonant frequency shift due to variation in length of SWBNNT. Results shows that shorter nanotube resonators are more sensitive.

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