CHAPTER THREE

ELECTROSTATIC ACTUATOR DESIGN

3.1. Introduction:

Electrostatic actuator NEMS device is combining three fields electrical, thermal and mechanical structural. Itis generally consist of four main parts:

1- Base layer.

2- Isolator layer.

3- Actuator layer.

4- Pad layer.

3.1.1. Base layer:

This layer used for two purposes the first one is to complete the electrical circuit by being the ground of the circuit, also this layer used as a base to carry the other parts of actuator. It is made of semi-conductors, either silicon semi-conductors, or any other, the dimensions of this layer are (200×2×20) μm.

3.1.2.Isolator layer:

This one is located between base and actuator layers, it has specific function which is the isolating the electrical current this makes voltage difference between base and actuator layers by this difference the actuation takes place. This layeris made eitherof silicon dioxide (SiO_2) or any other isolator; the dimensions of this layer are (50×3×20) μm.

3.1.3. Actuator layer:

This layer is located on isolator layer between isolator and pad layers this layer is the most important layer it control actuator characteristics it is made of semi-conductors, either silicon, or any other semi-conductors, the dimensions of this layer are (200×2×20) μm.

3.1.4. Pad layer:

This layer is placed at the top of the actuator; on its surface the main electric supplier is attached. It is made of material which has high electrical conductivity such as copper, silver and aluminum; the dimensions of this layer are (200×2×20) μm.

3.2. The programming:

After selection structural, thermal and electric as references ANSYS program has three major steps for analysis:

3.2.1. Pre-process:

This section of program includes:-

3.2.1.1. Element type:

Element type represent the required shape of element , it Is specified by the mesh dimension either 1D,2D OR 3D, also it is governed by analysis field , solid 227 has been used as element type.

3.2.1.2. Material properties defining:

ANSYS treat the material according to its properties which makes the definition ofmaterial properties accurately very important to have good result the following table shows the material properties:

Table (3.1) Material properties used in Design

properties / material	Elastic Modules (MPa)	Poisson's Ratio (PR)	Density (Kg/μm^3	Thermal Expansion Coefficient t(α),1/c	Thermal Conductivity (K),pW/µm°c	Resistivity (R) (ohm-µm)
SI	$185e^3$	0.28	$23e^{20}$	$2.33e^{-6}$	$157e^6$	$64e^{-4}$
SIO2	$73e^3$	0.23	$22.7e^{20}$	$0.5e^{-6}$	$1.4e^6$	$1e^{14}$
CU	$110e^3$	0.34	$89e^{20}$	$16.56e^{-6}$	$393e^6$	$1.72e^{-14}$

3.2.1.3. Geometry:

ANSYS provide two methods for geometry by importing it from drawing programs or by drawing in ANSYS, The following Figure (3.1) is show the drawn geometry.

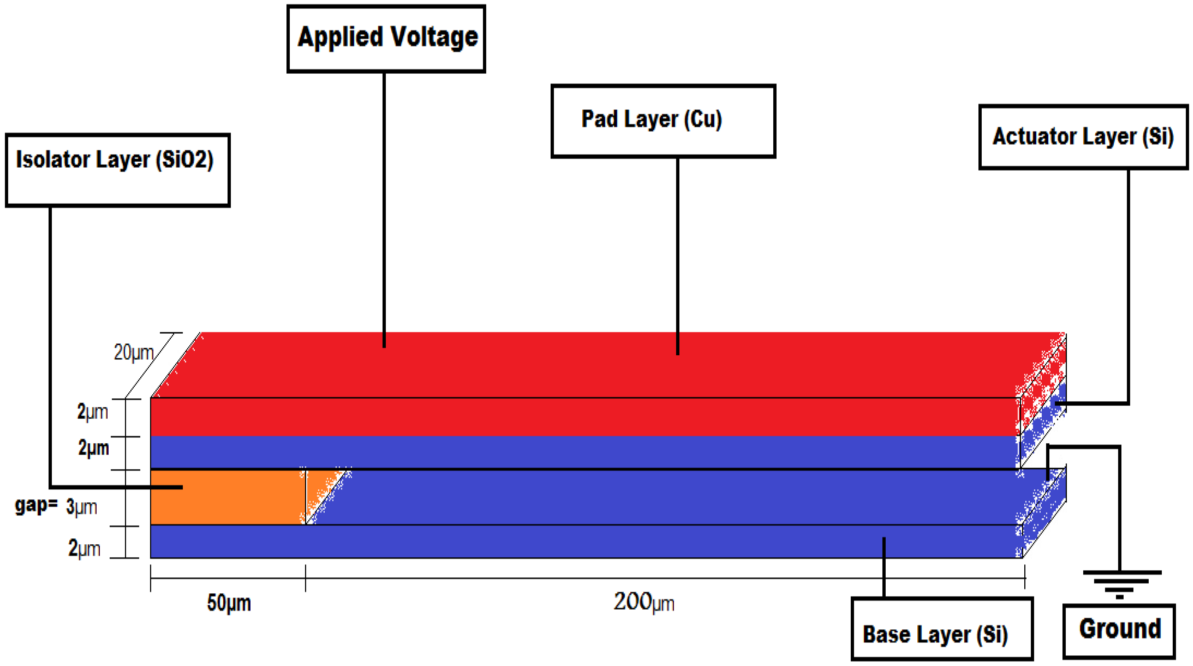

Figure (3.1): Drawn geometry for Micro-Cantilever

3.2.1.4. Mesh:

FEM works on dividing the model to small elements, this element are divided by many points which named as nodes. Nodes are considered as center of element and all parameters are calculated, this whole process is termed as mesh. ANSYS meshes each part of actuator separately with it specific properties, this process is termed as attributed mesh, the shape of mesh is selected as (tetra) and the size of element is selected by ANSYS APDL as defaluts. The following Figure (3.2) shows attributed mesh.

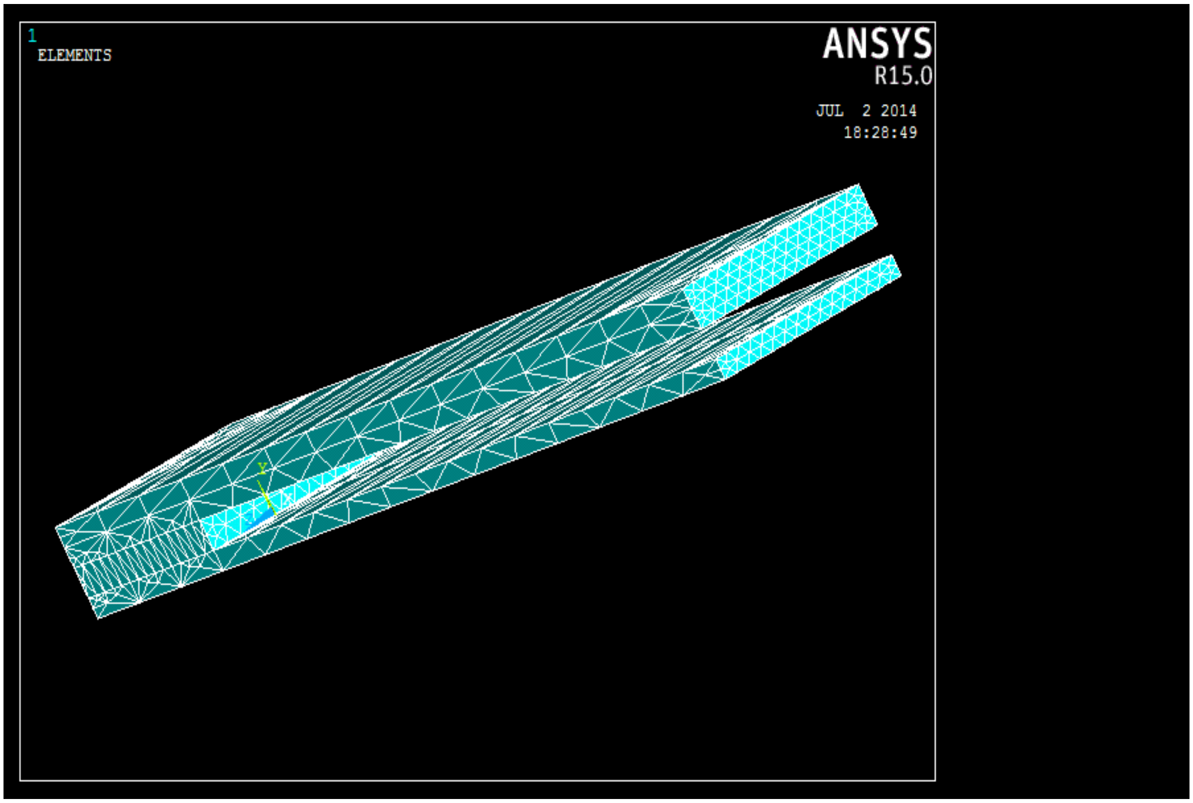

Figure (3.2): Mesh by ANSYS for Micro-Cantilever Design

3.2.2. Solution:

A- Analysis Type:

In this part of program you have to select your type of analysis, that depend upon which parameter you want to preview, in this research static and modal analysis was selected as analysis type.

B- Load Definition:

In this stage both electrical and structural loads are applied. The following Figure (3.3) represents geometry with applied load.

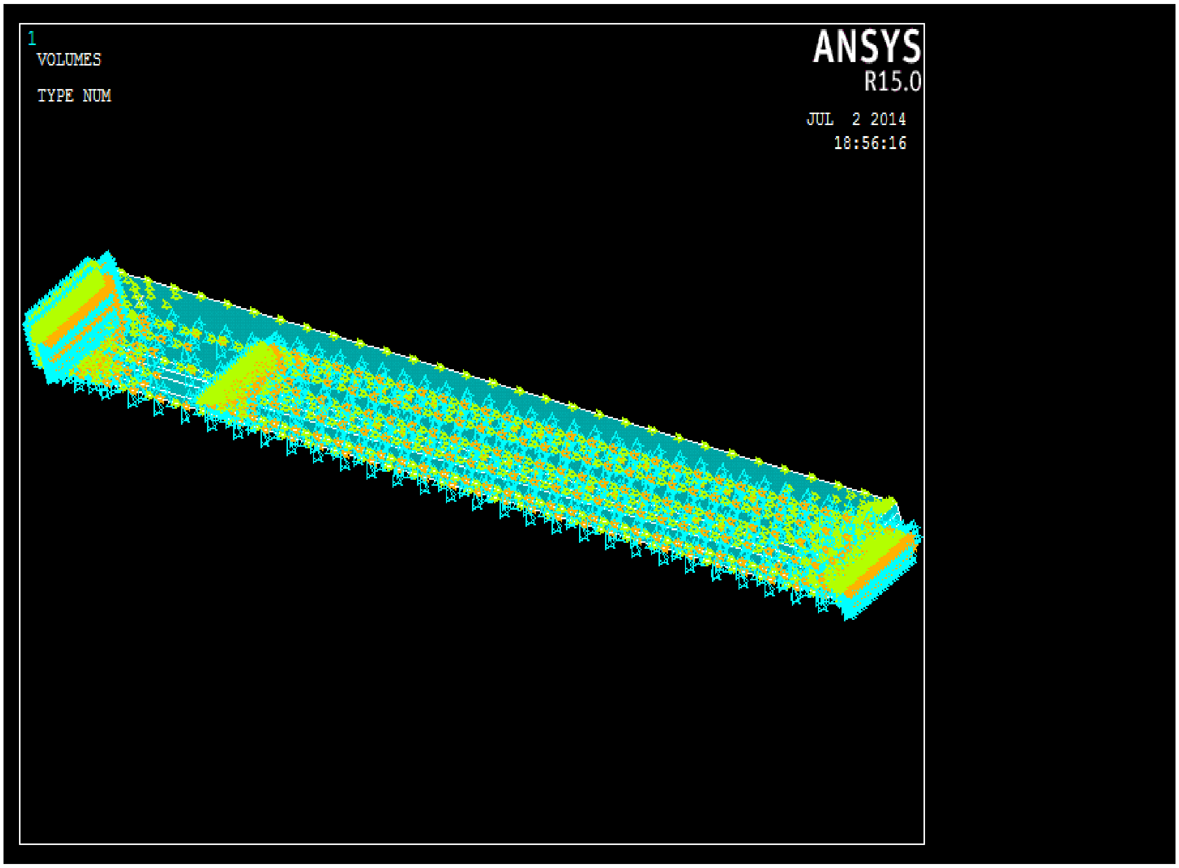

Figure (3.3): Geometry with Applied load

C- Solve:

This part in program like RUN,that executes all the commands and parameters which entered.

3.2.3. Post process:

In this part the program allows to the user to plot the results of analysis, which will be showed in chapter four.

3.3. Effect of the Electrode Position on the Natural Frequency:

It was compare the natural frequency which has been calculated by analytical method with that one which has been calculated by ANSYS.

❖ **Modal Validation:**

Natural frequency by analytical methods given by:[2].

$$f = 0.16 * \frac{t}{l^2} * \sqrt{\frac{E}{\rho}} \text{Equ.(3.1)}$$

f=Natural frequency (Hz).

E= Elasticity modulus (Pa).

ρ= Density (kg/m³).

t= thickness (m).

l=length (m).

$$E_{eq} = \frac{\sum l}{\sum_{i=1}^{2} \frac{li}{Ei}}$$

$$E_{eq} = 137.966*10^9 \text{ N/m}^2$$

$$\rho_{eq} = n\rho_1 + [1-n]\rho_2 = 5600 \text{ kg/m}^3$$

3.3.1.Natural frequencyby analytical methods for 100% of cantilever covered with electrode pad: (L=200µm)

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.2 * 10^{-3}]^2} * \sqrt{\frac{137.966 * 10^9}{5600}}$$

= 79.4167 KHz

3.3.1.1Natural frequency by ANSYS for 100% of cantilever covered with electrode pad show in Figure (3.4):

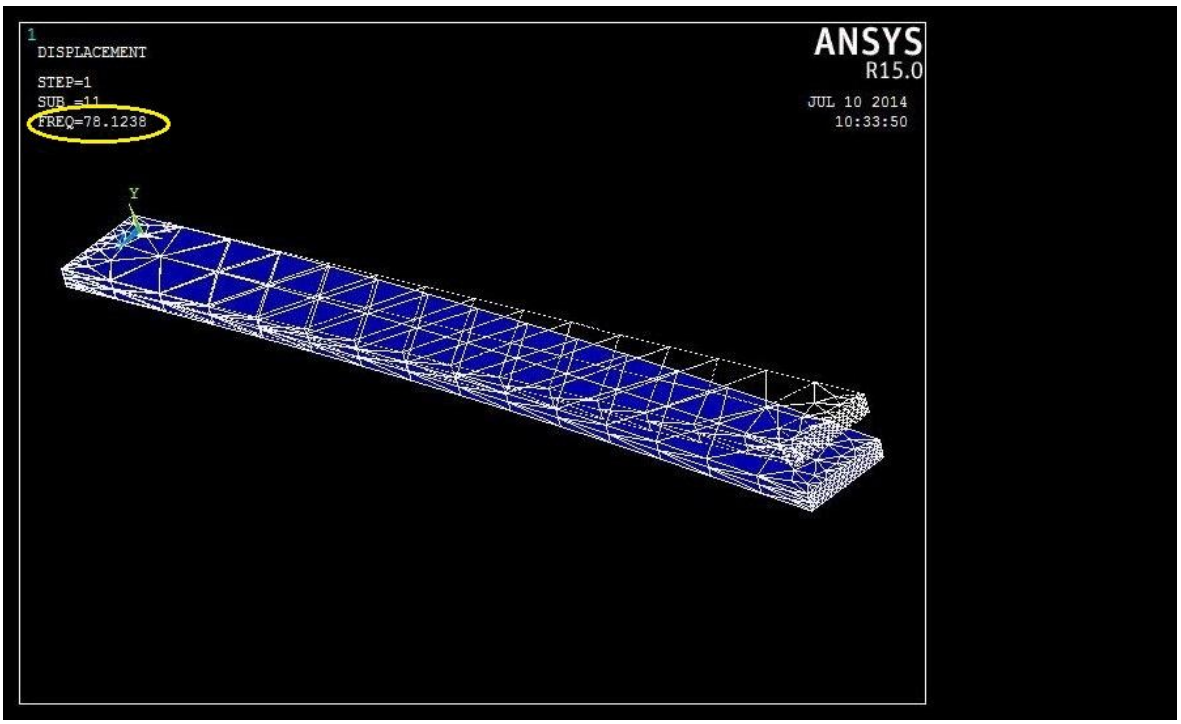

Figure (3.4): Natural frequency by ANSYS for (L=200µm)

Notice that the value of natural frequency is 78.1238 KHz.

Error in frequency:-

$$\Delta f = \frac{f_{analytical} - f_{ansys}}{f_{analytical}}$$

$$=\frac{79.4167-78.1238}{79.4167} = 0.01628 = 1.628\%$$

From this calculation wasfound that the error as percentageis 1.628% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.2.Natural frequency by analytical methods when(L=180µm):

$$E_{eq}=139.8373*10^9 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.18 * 10^{-3}]^2} * \sqrt{\frac{139.8373 * 10^9}{5600}}$$

$$= 98.708 \text{ KHz}$$

3.3.2.1 Natural frequency by ANSYS when (L=180µm)show in Figure (3.5):

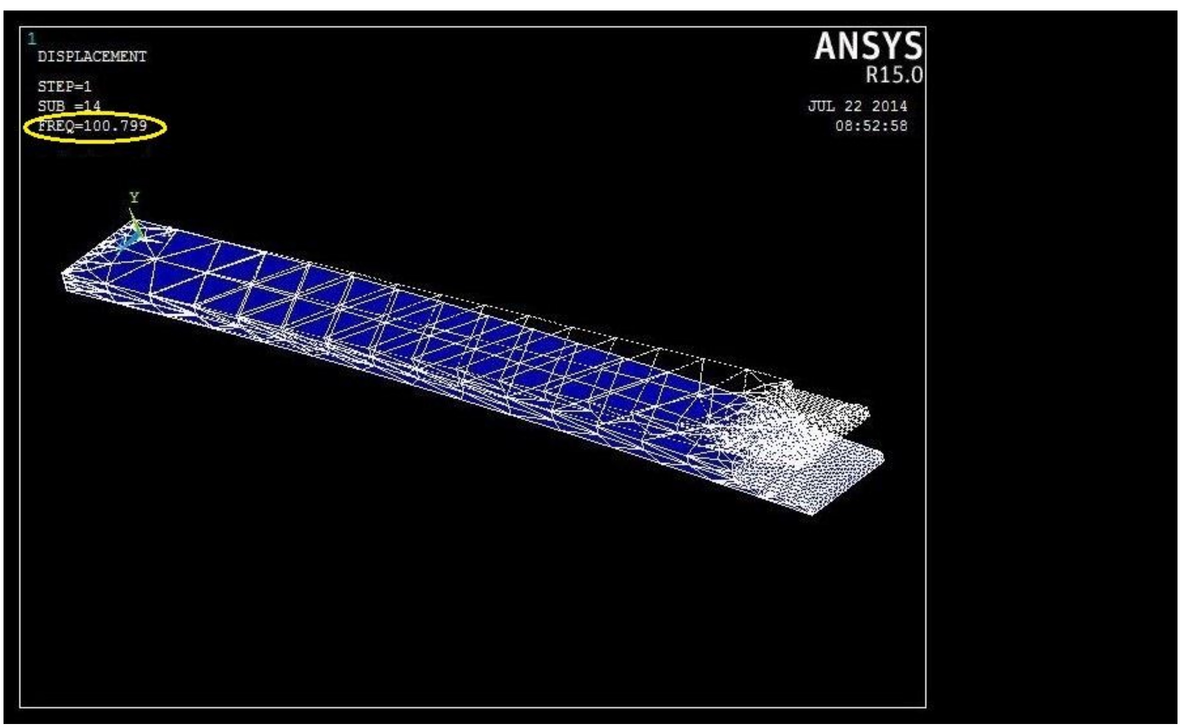

Figure (3.5): Natural frequency by ANSYS for (L=180µm)

Notice that the value of natural frequency is 100.799 KHz.

Error in frequency:-

$$=\frac{100.799-98.708}{100.799} = 0.02074 = 2.074\%$$

From this calculation was found thatthe error as percentage is 2.074% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.3.Natural frequency by analytical methods when (L=160μm):

$$E_{eq} = 141.9767 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.16 * 10^{-3}]^2} * \sqrt{\frac{141.9767 * 10^9}{5600}}$$

$$= 125.879 \text{ KHz}$$

3.3.3.1 Natural frequency by ANSYS when (L=160μm)show in Figure (3.6):

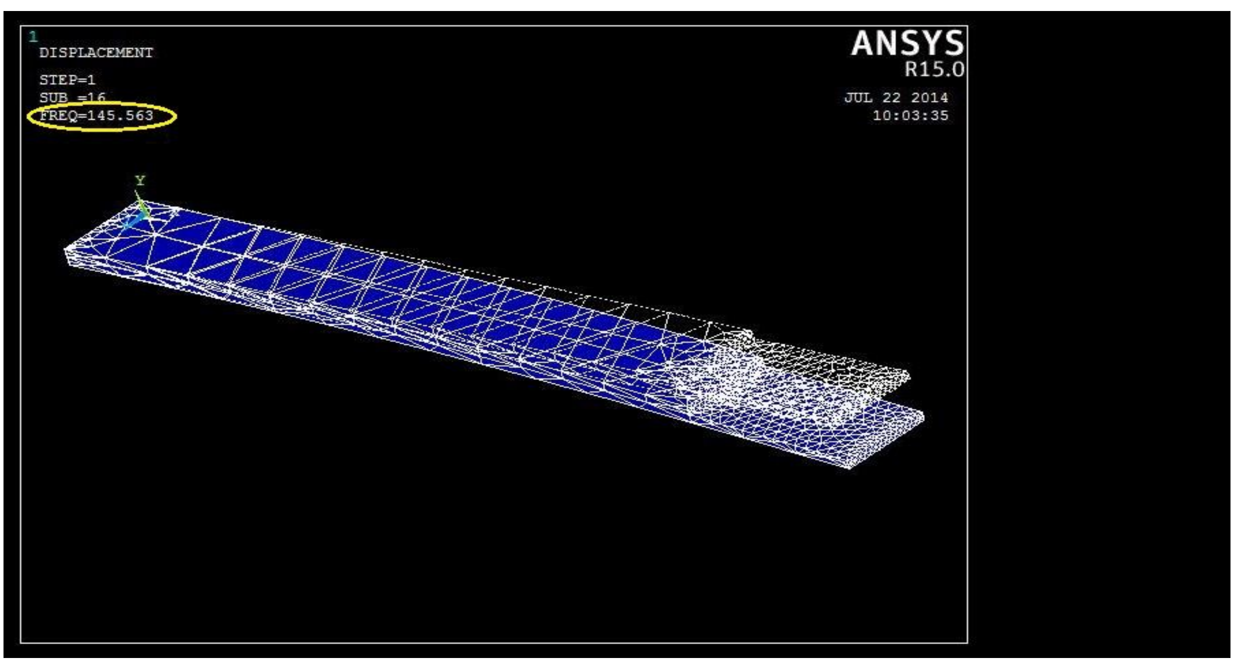

Figure (3.6): Natural frequency by ANSYS for (L=160μm)

Notice that the value of natural frequency is 145.563 KHz.

Error in frequency:-

$$=\frac{145.563-125.879}{145.563} = 0.1352 = 13.52\%$$

From this calculation was foundthat the error as percentage is 13.52% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.4. Natural frequency by analytical methods when (L=140µm):

$$E_{eq} = 144.4468 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.14 * 10^{-3}]^2} * \sqrt{\frac{144.4468 * 10^9}{5600}}$$

$$= 165.837 \text{ KHz}$$

3.3.4.1 Natural frequency by ANSYS when (L=140µm)show in Figure (3.7):

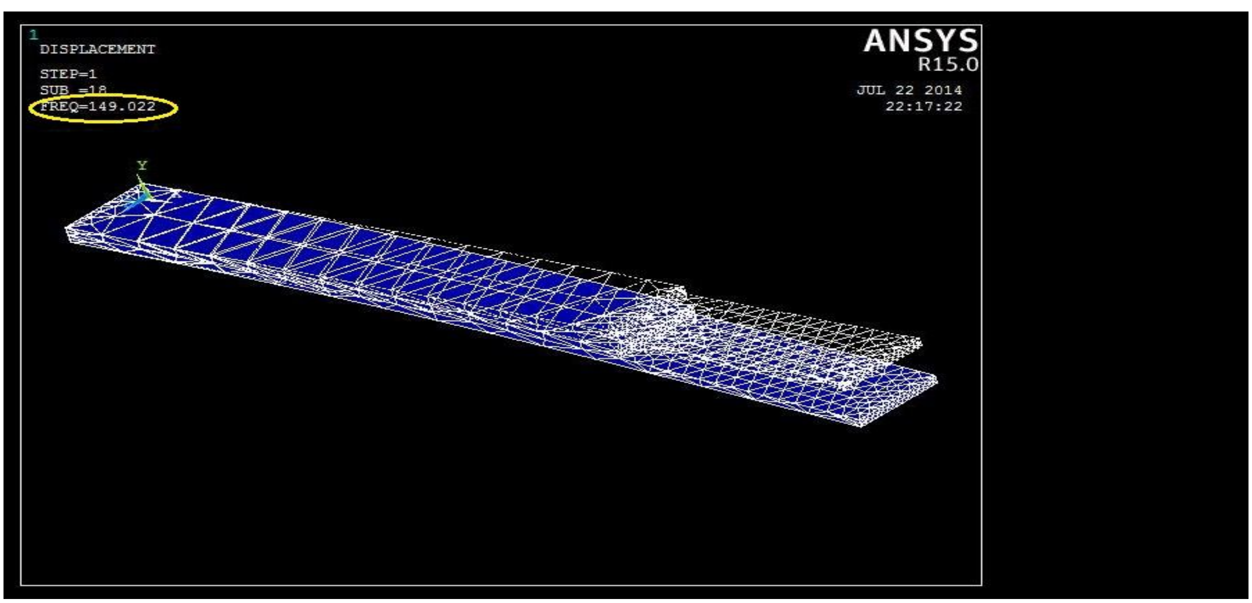

Figure (3.7): Natural frequency by ANSYS for (L=140µm)

Notice that the value of natural frequency is 149.002 KHz.

Error in frequency:-

$$=\frac{165.837-149.002}{165.837} = 0.1015 = 10.15\%$$

From this calculation was found that the error as percentage is 10.15% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.5. Natural frequency by analytical methods when (L=120µm)

$$E_{eq}=147.3303 * 10^9 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.12 * 10^{-3}]^2} * \sqrt{\frac{147.3303 * 10^9}{5600}}$$

= 227.965 KHz

3.3.5.1 Natural frequency by ANSYS when (L=120µm) show in Figure (3.8):

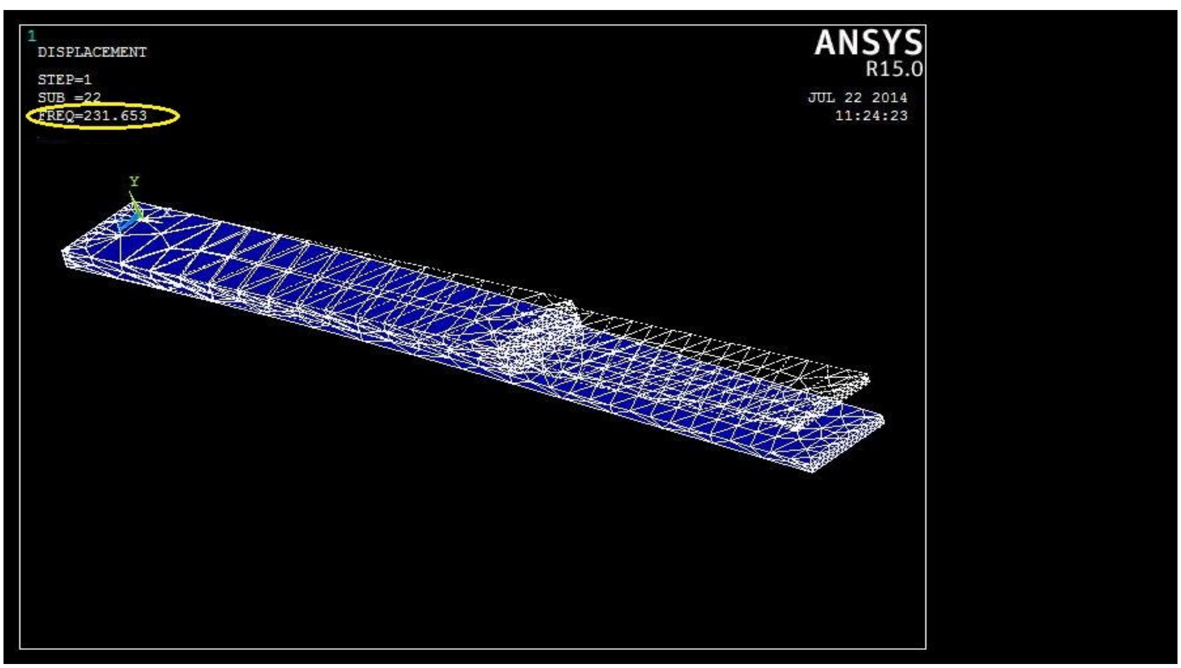

Figure (3.8): Natural frequency by ANSYS for (L=120µm)

Notice that the value of natural frequency is 231.653 KHz.

Error in frequency:-

$$=\frac{231.653-227.965}{231.653} = 0.0159 = 1.59\%$$

From this calculation was found that the error as percentage is 1.59% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.6. Natural frequency by analytical methods when (L=100µm):

$$E_{eq}=150.7407 * 10^9 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.10 * 10^{-3}]^2} * \sqrt{\frac{150.7407 * 10^9}{5600}}$$

$$= 332.048 \text{ KHz}$$

3.3.6.1 Natural frequency by ANSYS when(L=100µm)show in Figure (3.9):

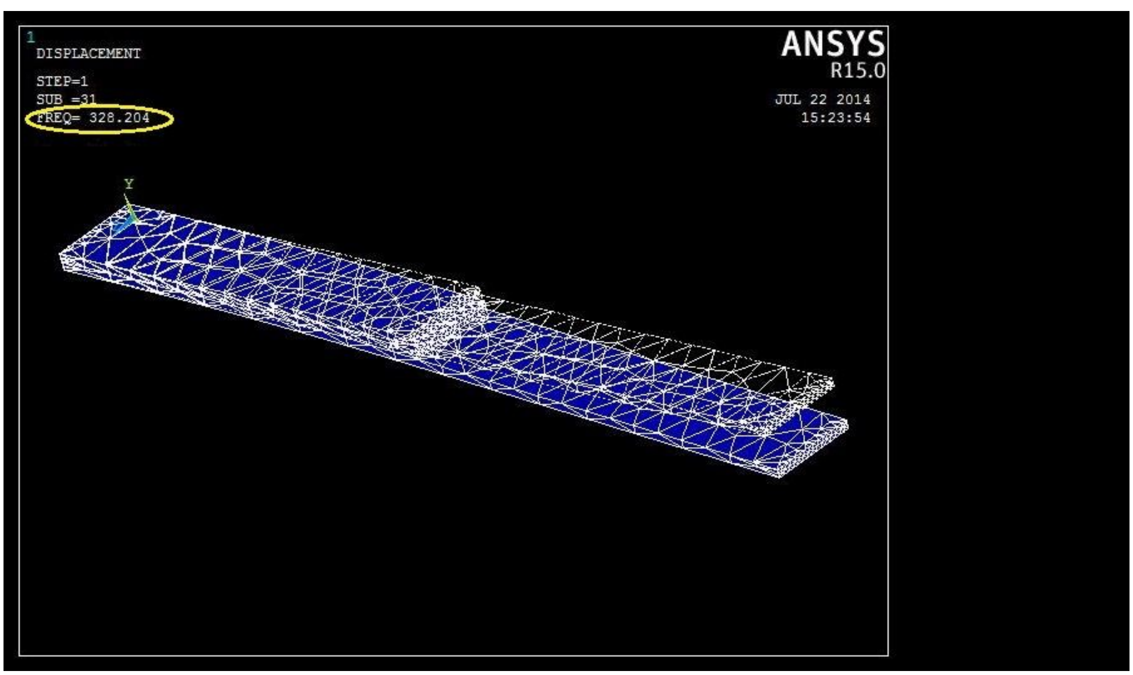

Figure (3.9): Natural frequency by ANSYS for (L=100µm)

Notice that the value of natural frequency is 328.204 KHz.

Error in frequency:-

$$=\frac{332.048-328.204}{332.048} = 0.0116 = 1.16\%$$

From this calculation was found that the error as percentage is 1.16% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.3.7. Natural frequency by analytical methods when (L=80µm):

$$E_{eq}=154.8370 * 10^9 \text{ N/m}^2$$

$$f = 0.16 * \frac{0.004 * 10^{-3}}{[0.08 * 10^{-3}]^2} * \sqrt{\frac{154.8370 * 10^9}{5600}}$$

$$= \underline{525.827} \text{ KHz}$$

3.3.7.1 Natural frequency by ANSYS when (L=80µm) show in Figure (3.10):

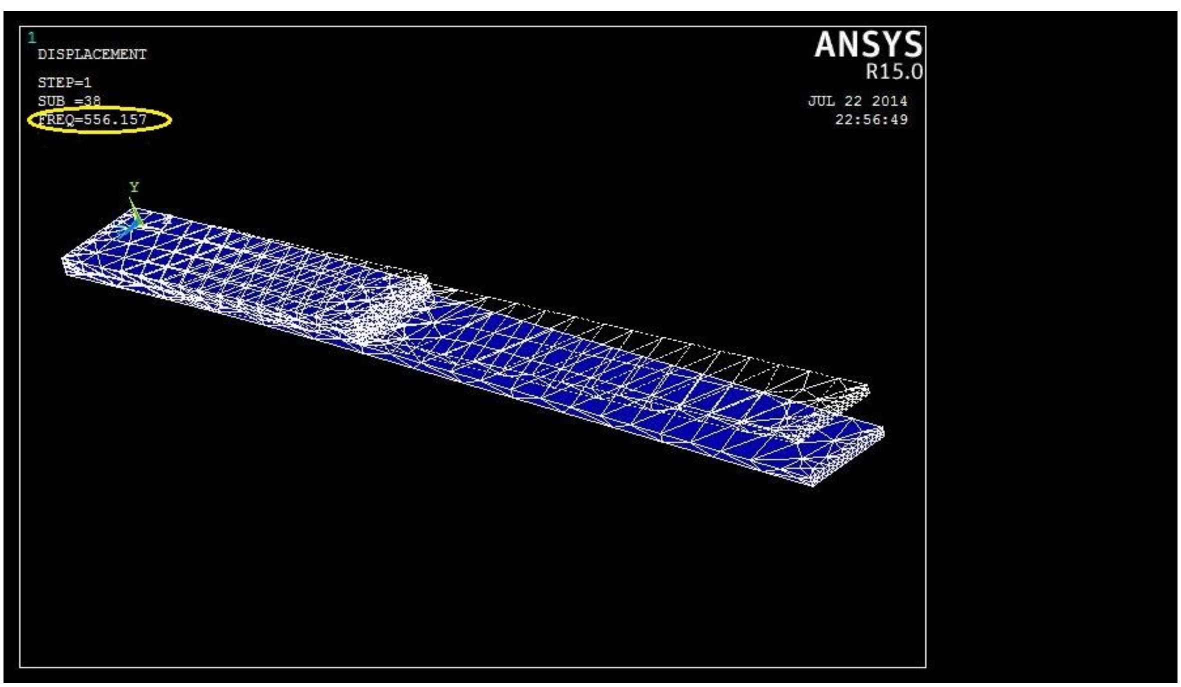

Figure (3.10): Natural frequency by ANSYS for (L=80µm)

Notice that the value of natural frequency is 556.157 KHz.

Error in frequency:-

$$=\frac{556.157-525.827}{556.157} = 0.05453 = 5.453\%$$

From this calculation was found that the error as percentage is 5.453% and this refers to the accuracy of formula used by ANSYS to calculate the natural frequency.

3.4. Natural frequency Simulation Results:-

The below table shows gained results:

Table (3.2): Natural frequency result

% of cantilever covered with Electrode pad	Electrode Length(μm)	Natural Frequency(KHz) By ANSYS	Natural Frequency(KHz) By Calculation	Error for Natural Frequency (%)
100	200	78.1238	79.4167	1.628
90	180	100.799	98.708	2.074
80	160	145.563	125.879	13.52
70	140	149.002	165.837	10.15
60	120	231.653	227.965	1.59
50	100	328.204	332.048	1.16
40	80	556.157	525.827	5.453

- The above table shows the natural frequency by both (ANSYS & Calculation) and error between them for different positions of the electrode Pad; the errors shown are different for different positions, because the mesh of geometry in ANSYS is different in each design.