Simulation of an AlN Thin Film Resonator for High Sensitivity Mass Sensors

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Introduction:

Piezoelectric thin films are one of the popular components in sensors [1]. Piezoelectric acoustic resonators earn a greater requirement in the field of thin film piezoelectric sensors [2]. Due to the rise of nanotechnology, the necessity of smaller dimension with greater sensitivity is repeatedly coming into picture [3]. Here the objective is to show the high sensitivity of a piezoelectric thin film when its thickness is decreasing towards lower nanoscale regime. The aluminium nitride (AlN) thin film is used as the piezo-material placed between two electrodes fixed in two ends.

Figure 1. Resonating structure of aluminium nitride thin film suspended on an etched cavity.

Computational Methods:

- Two dimensional modelling is done in COMSOL.
- The aluminium nitride thin film is suspended on a cavity etched on a silicon substrate.
- The thin film is placed between two aluminium electrodes.
- The dimensions used in the structure are represented in Table 1.
- Eigenfrequency analysis is done of the structure.
- Initially the fundamental frequency is obtained without external mass and then the frequency is observed after adding external mass.
- Resonance frequency shift due to the added mass is calculated.
- Al_2O_3 is used as the external mass.

Parameters	Value	Units
Thin film length	140	nm
Electrode width	30	nm
Electrode thickness	30	nm
Cavity depth	20	nm
Silicon substrate length	200	nm
Area of cross-section of added mass	4	nm^2

Table 1. Different dimensions used in the structure

Boundary conditions used in the modelling:

- Both ends of the piezo-substrate are fixed.
- The silicon substrate is fixed in every boundaries.

Extremely-fine mesh is used.

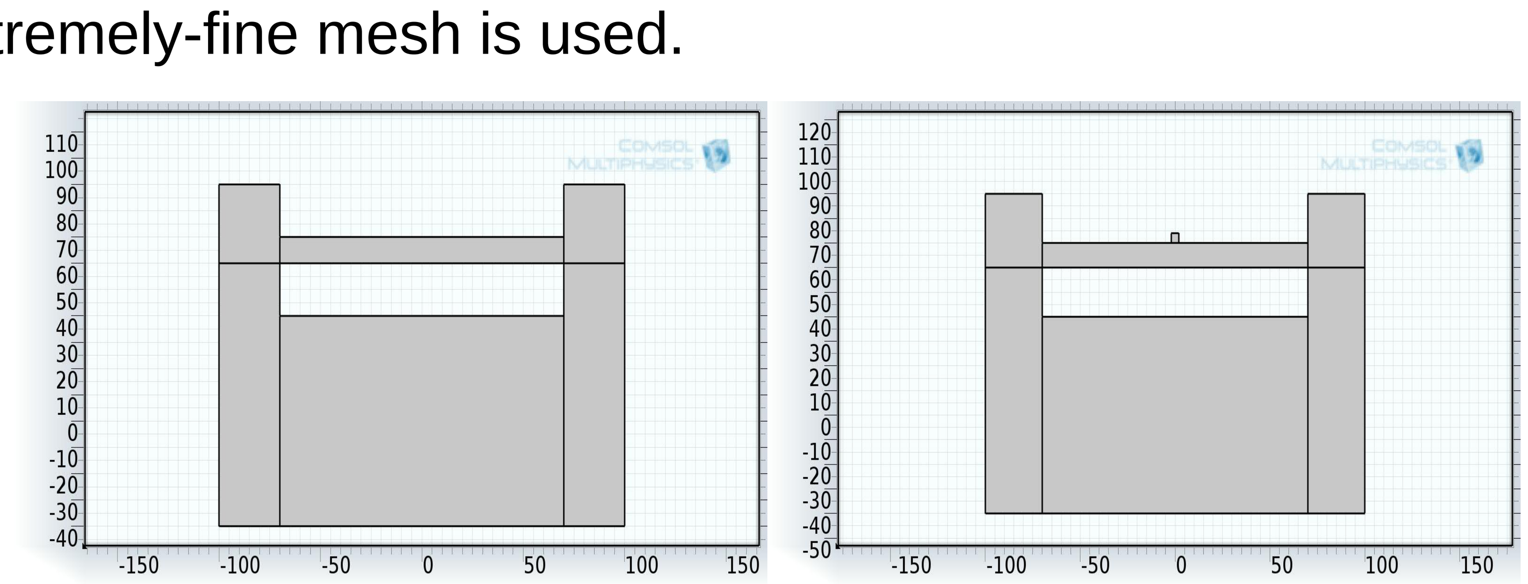

Figure 2. Structure without additional mass & with external mass Al_2O_3 added

Simulation Results:

The resonance frequency of the structure is calculated in both (with and without mass loading) condition for varying thickness of the piezoelectric substrate.

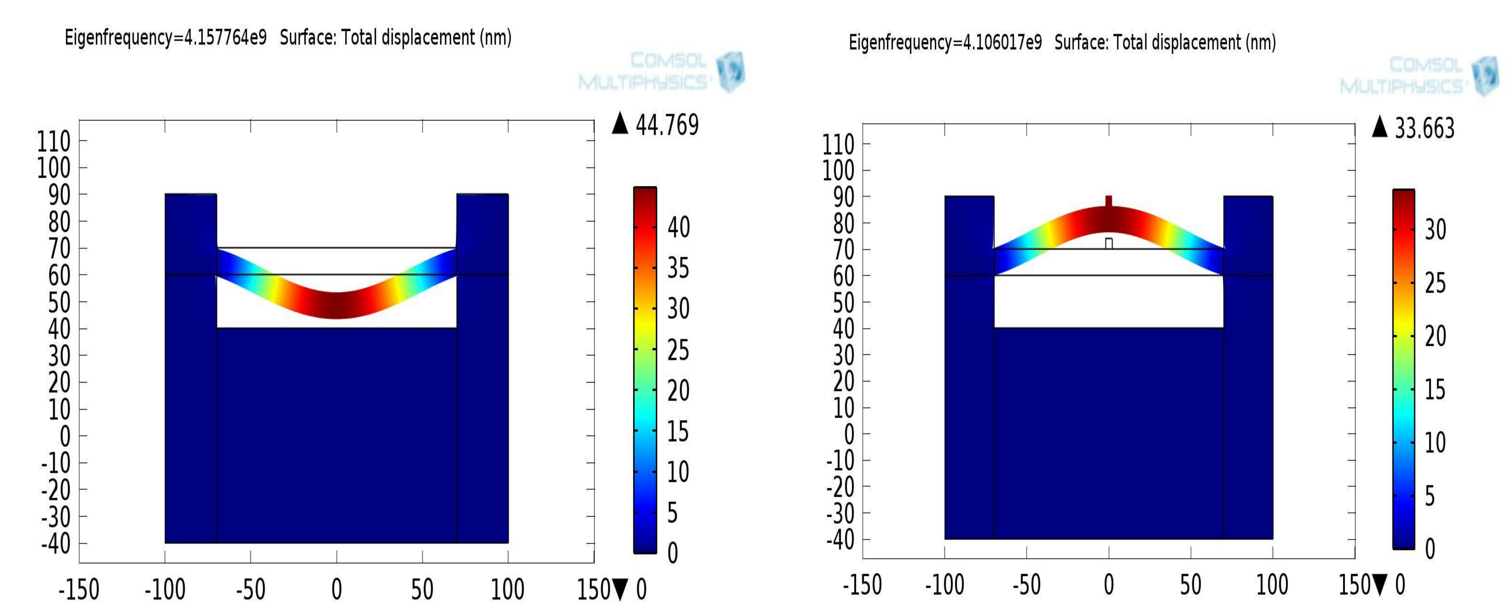

Figure 3. Displacement profile of the structure with and without mass loading at corresponding resonant frequencies for 10 nm thickness of piezo-substrate.

The frequency shift is observed when a mass is added on the structure.

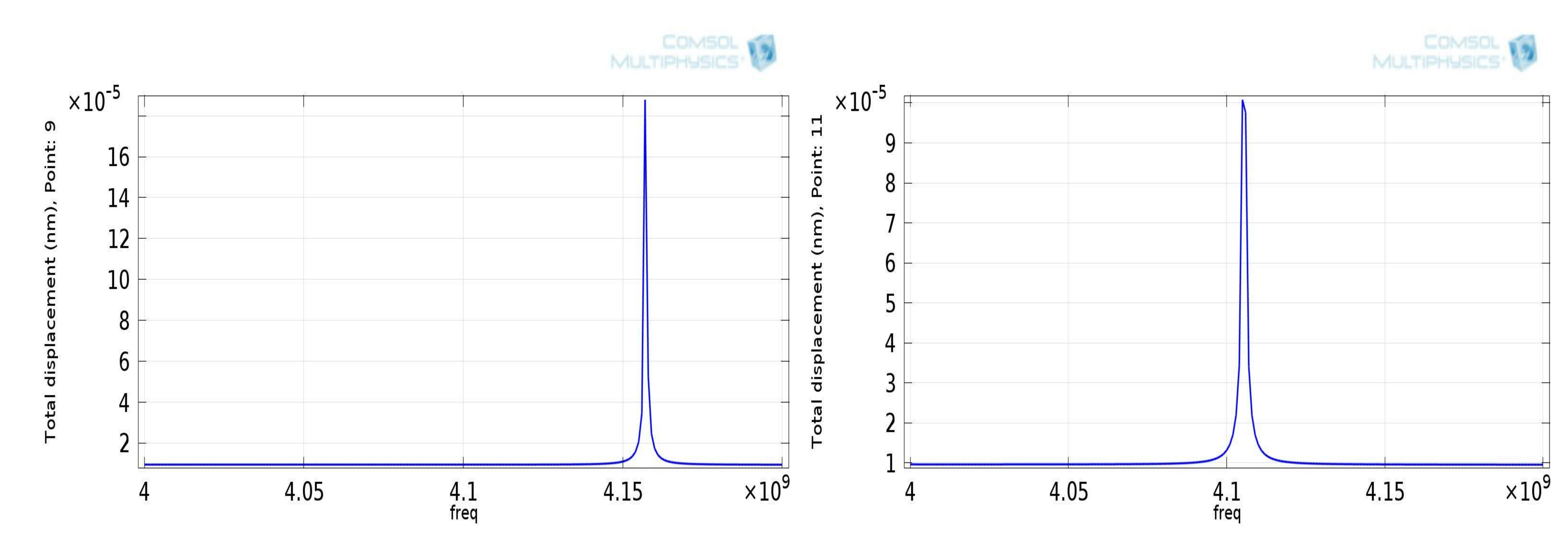

Figure 4. Shift in frequency due to the addition of 1.586 X 10^{-11} g/m mass.

The frequency shift is decreased when the thickness of the substrate is increased. The mass sensitivity of the device is reduced with the increase of the thickness of the thin film. The frequency shift with varying thickness is represented in Table 2.

Substrate thickness (nm)	Resonance frequency without mass (Hz)	Resonance frequency with mass (Hz)	Shift (Hz)	Mass Sensitivity ($Hz/kg.m^{-1}$)
10	4.157764 X 10^9	4.106017 X 10^9	5.1747 X 10^7	3.263 X 10^{21}
15	5.545067 X 10^9	5.500934 X 10^9	4.4133 X 10^7	2.783 X 10^{21}
20	6.592535 X 10^9	6.555082 X 10^9	3.7453 X 10^7	2.361 X 10^{21}
25	7.27987 X 10^9	7.248711 X 10^9	3.1159 X 10^7	1.965 X 10^{21}
30	7.673657 X 10^9	7.647918 X 10^9	2.5739 X 10^7	1.663 X 10^{21}

Table 2. Frequency shift & mass sensitivity for different substrate thickness

Conclusions:

It is observed that with the reduction of the thickness of piezoelectric aluminium nitride, the frequency shift due to the addition of mass is increased. Hence the mass sensitivity will be increased. If the piezo-material is ultra-thin like in a few atomic layers then much greater mass sensitivity is expected.

References:

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3. K. Eom, H. S. Park, D. S. Yoon, T. Kwon, Nanomechanical resonators and their applications in biological/chemical detection: nanomechanics principle, Elsevier Physics Reports, Volume 503, pp. 115-163 (2011).