High Frequency Resonators Using Exotic Nanomaterials

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Abstract

Introduction

Human made mechanical resonators have been around for a thousand years [1]. Early applications included musical instruments and chronographs operating in millihertz to kilohertz frequencies while more recent interest has turned ultra-high frequency resonators and oscillators suitable for wireless technologies, mass sensing and even biological applications [2-9]. The trend has been towards small, stiff and low mass from micro-electro-mechanical systems towards nano-electro-mechanical systems. There has been examples of reports of using mechanical resonators for myriad of applications including mass sensing, charge detection, biosensing and RF communications [2, 6, 8-13]. New nano-materials such as carbon nanotubes, graphene, zinc oxide nanobelts, and silver-gallium nanowires are good candidates for high frequency mechanical nanoresonators due to their excellent physical properties and therefore is the subject of this study using COMSOL Multiphysics® models. Developing models in COMSOL for new exotic nanomaterials can help in validation of such materials for myriad of applications as mentioned above.

Use of COMSOL Multiphysics®

Structural mechanics module was used to model nano resonators using materials such as carbon nanotubes, Ag2Ga nanowires and ZnO nanobelt as a simple 3D cantilever beam in COMSOL. Frequency domain analysis was used to develop a frequency response function for the nano resonator. Clamp-free was considered as the boundary conditions of the beam and base motion vibration with ~500 nm amplitude has been applied as the input. Mechanical damping function was imported into the finite element model by defining loss factor that is equal to inverse of quality factor. Although COMSOL has beam element, nano resonator was meshed with 3D cubic element that is elongated along the axis of the beam.

Results

Figure 1 compares the frequency response of Ag2Ga, ZnO, and carbon nanotube resonators that resulted from COMSOL with experimental data reported in references [14-16]. The experimental graph peaks were normalized to their relevant simulations peaks. The resonance frequencies of simulations graphs are in match with experimental data and maximum difference between

resonance frequencies resulted from COMSOL and the reported experimental data was within ~4.1% for the fourth mode of the resonance frequency for silver- gallium nano needle. On the otherhand, ZnO nanobelts had the maximum amplitude at the first mode suggesting material property dependence of resonance frequencies. This new COMSOL model can be conveniently used to predict the behavior of new developed materials like nano-diamond, graphene, boron-nitride and other exotic 2-D nanomaterials using COMSOL without extensive experimentation.

Conclusion

Materials such as nanotubes and graphene are interesting candidates for high frequency mechanical resonator applications. Hundreds of 2-D nanomaterials are in study for applications ranging from mass sensing, chemical sensing, transistors and actuation. However experimentation of each nano-material for mechanical resonance frequency would be time consuming and prohibitively expensive task. The model suggested here can be useful for evaluating candidate materials for nano-resonator applications based on their resonance frequency, stored elastic energy and Von Mises stress criterion. Our preliminary results suggest that this model can predict the resonance frequency of first five modes within ~5% error margins. Additional thermal criterion can be implemented in COMSOL which can expand the scope of the model for all the applications mentioned above.

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Figures used in the abstract

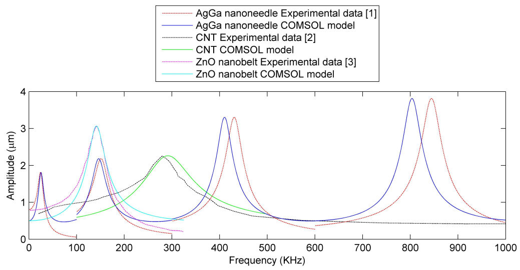

Figure 1: Frequency response of nano-mechanical resonators using exotic nanomaterials.