Acoustic-Mechanic Modeling Of Polydimethylsiloxane In The MHz Regime For Metamaterials Applications

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Abstract

Polydimethylsiloxane (PDMS) is a biocompatible material widely used in biomedical applications such as implantable sensors. A realistic modeling of PDMS in acoustic-mechanic simulation is useful especially for medical applications which use ultrasonic waves as interrogation source. However, a realistic acoustic simulation of PDMS as material is challenging due especially to its frequency-dependent behavior. PDMS is a viscoelastic material that exhibits a power-law attenuation-frequency relationship.
In this work, we illustrate the results of an acoustic-mechanic frequency model for PDMS and compare it to experimental results. As initial structure, we simulated a bilayer made of PDMS and silicon (Si) in water, and compared the amplitude of the reflection spectrum with the known analytical solution. With this comparison, we have validated the material properties definition of the PDMS in the frequency domain of interest. In a second step, we introduced a more complex structure consisting of a metamaterial, made of a Si pillar embedded in PDMS, and the, compared the simulated amplitude of the reflection spectrum with experimental data.
For this case of study, we use two interfaces: the Solid Mechanics and the Pressure Acoustics one; the former is used in the domain definition of the bilayer and metamaterial, the latter is used to define and model the water domain. At their interfaces, their coupling is introduced with an acoustic-structure boundary available from the Multiphysics module.
Experimental literature values in the ultrasonic regime (3-7 MHz) of the complex speed of sound of PDMS have been used in order to express univocally its elasticity in the Linear Elastic Material node. Their value has been interpolated in the definition section as function of the frequency with experimental data.
Perfect Matched Layers (PML) have been expressed in the definition section as artificial domains, with cartesian definition, in order to suppress reflection artefacts arising from the spatial limitation of the water domains. The periodicity of the whole domain has been simulated with Floquet boundary conditions at the external edges of the model.
The incident pressure field has been defined in the upper water domain as frequency dependent plane waves, with vertical incident angle. Last but not least, a customized frequency-dependent mesh has been optimized defining as maximum element size a fraction of the acoustic wavelength in the specific domain.
The reflection spectrum of the bilayer structure follows the trend of the higher acoustic impedance layer (Si), while the frequency spacing of the frequency peaks (maxima) are inversely proportional to the PDMS layer thickness. Furthermore—through the definition of the complex acoustic properties of the speed of sound of PDMS—it is also possible to elucidate the contribution of the attenuation in the higher frequencies regime, ascribable to the attenuation in the PDMS layer, increasing with the frequency. These findings are useful also for other frequency-dependent applications, where PDMS is used as a constituting material in the ultrasonics domain.

Reference

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Figures used in the abstract

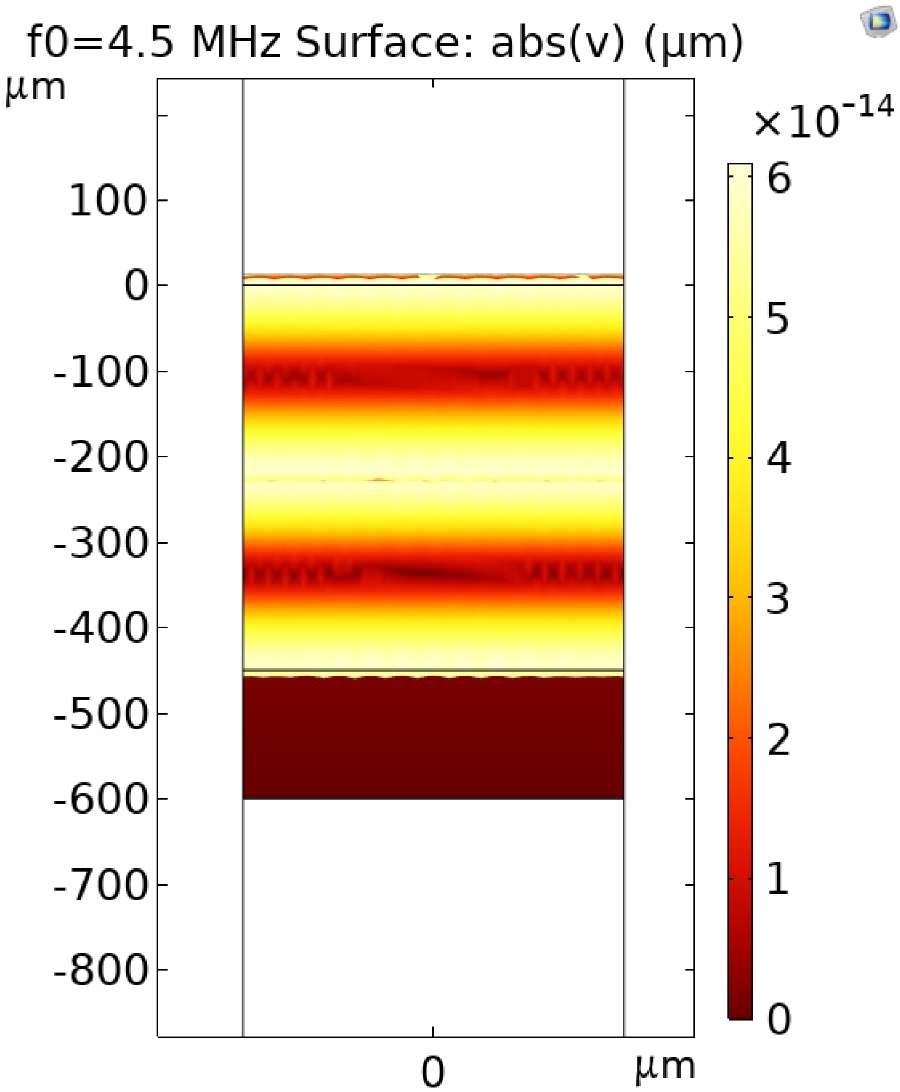

Figure 1 : Absolute value of vertical displacement field (v) in the bilayer structure with longitudinal waves visible in the vertical direction.

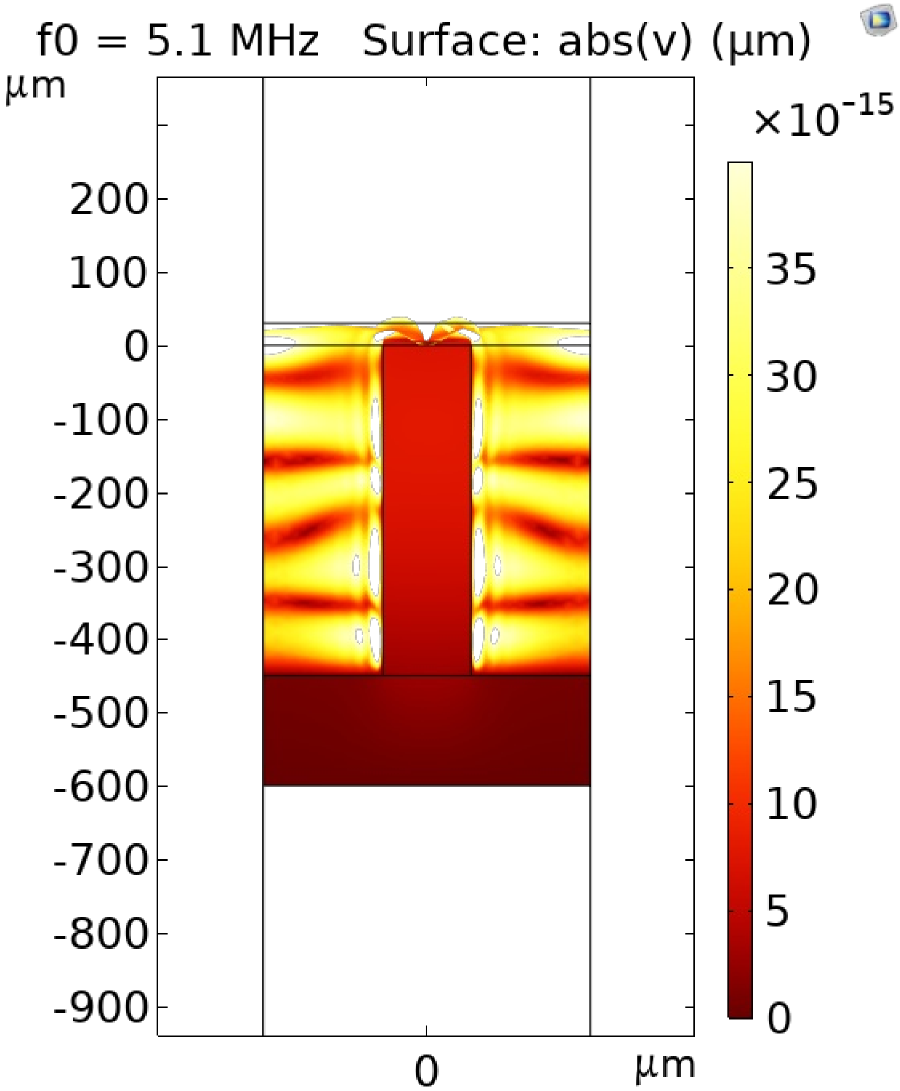

Figure 2 : Absolute value of vertical displacement field (v) in the metamaterial structure, with additional shear waves developing at the interface between the silicon pillar and the PDMS.