Ultrasound Pressure Field of a Resonating Piezoelectric Membrane with Three Excitation Electrodes

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Abstract

Micromachined ultrasound transducers can work as a sensor or actuator for measuring fluid speed and direction, mixing and exciting particles (sonication), taking images (ultrasonography), non-destructive testing and many other purposes in various fields.
In this work, a COMSOL Multiphysics® 3D-model of a piezoelectric membrane has been built. It consist of a circular 80um wide AlN layer in between two top and one bottom Al electrodes, and a conformal passive SiO2 top layer, all immersed in a fluid domain where the pressure field propagates. The model uses multi-physics coupling between Acoustics, Solid Mechanics and Electrostatics. Four studies were performed and compared with experimental results. Firstly, a "Stationary Study" that computes the initial bending of the membrane due to the fabrication's residuum stress caused by thermal deformation. Then, an "Eigenvalue Study" that computes the resonance frequencies of the device in vacuum. A "Frequency Domain Study" is used for the detection of the fundamental resonance peak at different acoustic medias, namely air and Fluorinert (FC-70). Finally, a "Time-Domain Study" represents the experimental setup in our lab where several voltage pulses are applied to the terminals and a probe is measuring the acoustic signal at 3.8mm from the transducer. By using a non-trivial domain with a spherical radiation boundary conditions we were able to compute the pressure up to 4mm away from the device.
We have been working with three different actuation strategies in two different medias. More precisely, the transducer was excited by its inner or outer top electrode, or differentially where both top electrodes have anti-phase signals. The simulated media are air, and FC-70. Additionally, drum-displacement measurements of the membrane were performed at Polytec, Germany, also in air and FC-70.
The desired outcome was a well calibrated model that allows different geometries and materials to be investigated aiming at the optimization of the performance of the device. Thus, our model predicted the resonant frequency of the device in vacuum, air and FC-70. Other successful predictions were the Q factors of the device in different media as well as the most efficient excitation strategy. Also, the resulted membrane displacement and pressure field at 3.8mm are in good agreement with the experiment. The model has the ability to compare electrode designs, layers' thicknesses and layers' materials when aiming at an optimal ultrasound actuating or sensing performance.

Figures used in the abstract

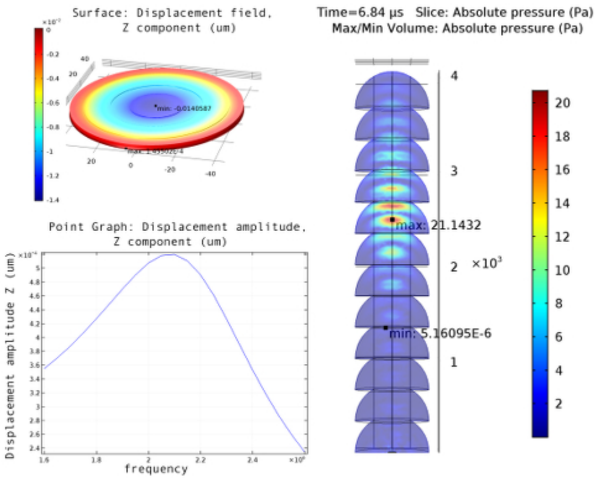

Figure 1: Simulations in Fluorinert FC-70. Up left, the initial displacement due to residuum stress: 14 [nm]. Low left, Displacement amplitude of the membrane center: 520 [pm] at 2.1 [MHz]. Right, absolute pressure from the Time Domain study, 21 [Pa] at distance 2.5mm.