Near-Field of Resonating Piezoelectric Membrane Used as Ultrasound Transducer

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Micromachined ultrasound transducers have wide range of applications [1]. As a sensor or actuator they can be used for measuring fluid speed and direction, to mix and excite particles (sonication), for taking images (ultrasonography), for non-destructive testing and many other purposes in wide variety of fields.

For this particular study, a simplified 3D model of micromachined piezoelectric membrane has been built. It consist of a circular Aluminium Nitride piezoelectric layer in between two Aluminium electrodes and an air or water domain where the pressure field propagates. The model of the transducer uses multi-physics coupling between Acoustics, Solid Mechanics and Electrostatics [2, 3, 4]. In a Stationary Study, the model computes the static displacement of the transducer membrane. Also, the frequency of the first resonance mode is computed by using the Eigenfrequency Study. As the resonant frequency matches with the experimental one, we proceed by using the Frequency Domain to take advantage of the Acoustics module and compute the pressure field produced by the transducer. The final goal is the simulated displacement and pressure field (see Figure 1 and 3) to be compared with the results from the experimental set up for validation.

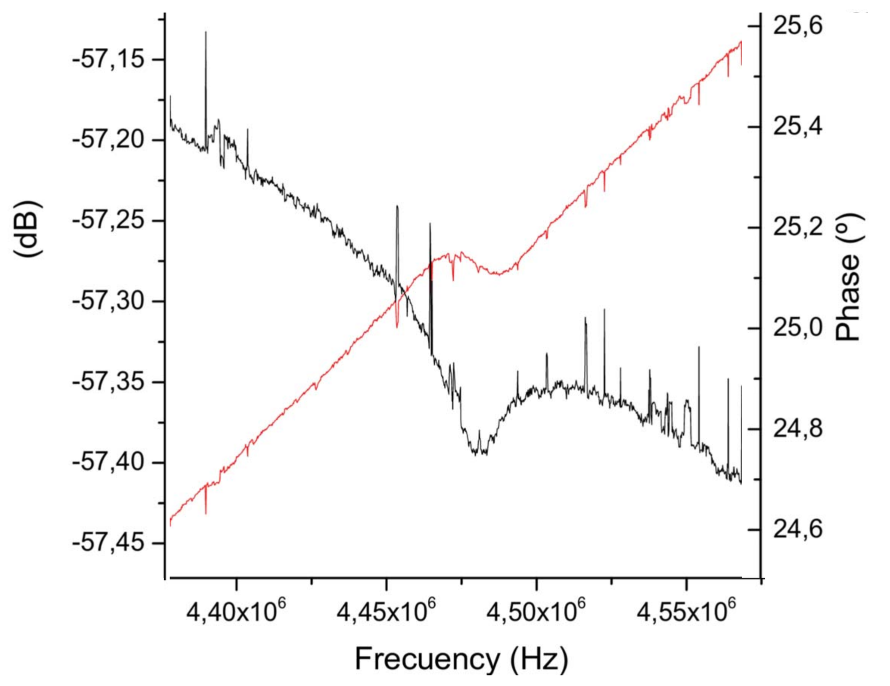

Figure 2: Electrical characterisation.

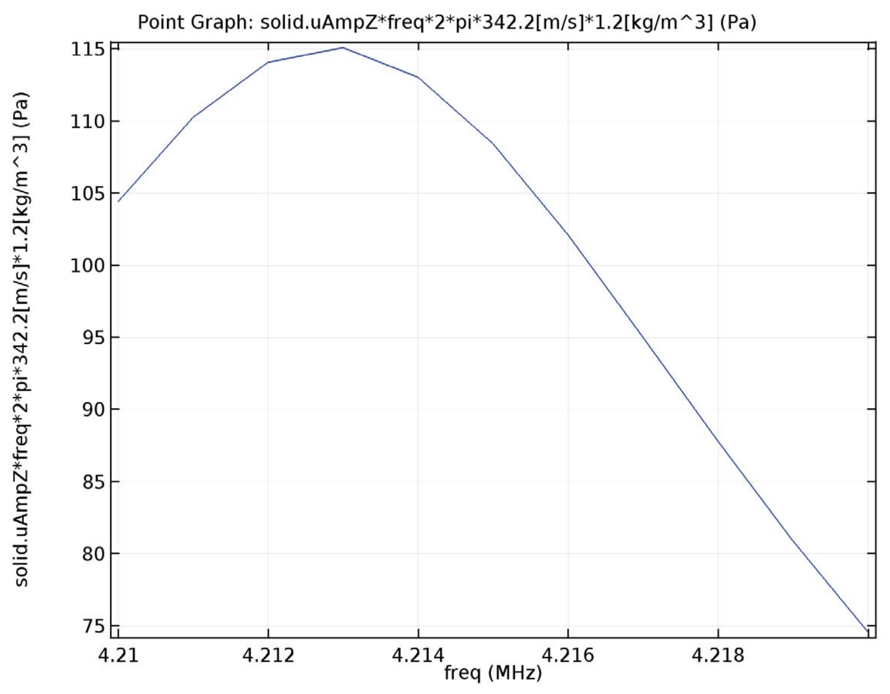

Figure 3: Simulated pressure above the center of the membrane.

Experiments and Simulations

The frequency response of the PMUT membrane is examined experimentally in a vacuum environment. The fundamental frequency of the modelled devices were characterised by using electrical and optical characterisation techniques. The resulted frequencies were between 4.47 [MHz] and 4.69 [MHz] depending of the different electrode geometries which was in line with the derived 4.21 [MHz] by the model; see Figure 2 and 3 above.

This model has the ability to examine design decisions of the top electrode for better ultrasound actuating and sensing. Also, how different thickness and radii of the membrane alter the performance, and finally, how the internal damping [4] of the aluminium electrodes can play role at high frequencies.

Layers bott->top [um]	Passive layer [um]	Cross cavity [um]	Damping	Press [Pa]	Dyn.Displ. [um] /1[V]	1st mode [MHz]	Static displ. [um]/1[V]
Al 0.4 AlN 1.3 Al 0.35	no	no	no	154.1	0.0112 at 4.14[MHz]	4.283	air 2.9e-5
Al 0.4 AlN 0.5 Al 0.35	yes SiO 1.5	no	no	190.5	0.01115 at 4.744[MHz]	4.839	air 2.6e-5
Al 0.4 AlN 0.5 Al 0.35	yes AlN 1.5	no	no	469	0.0185 at 6.66[MHz]	6.659	air 2.5e-5
Al 0.4 AlN 0.5 Al 0.35	yes SiO 1.5	yes offset 8 width 4	no	3913.4	0.256 at 4.622[MHz]	4.624	air 10.9047e-4
			Al layers $\eta = 0.0163$	1995	0.131 at 4.622[MHz]	4.748	10.905e-4
			no air			4.6	10.966e-4
Al 0.4 AlN 0.5 Al 0.35	yes AlN 1.5	yes offset 8 width 4	no	5535.3	0.277 at 6.349	6.743	5.439e-4
			Al layers $\eta = 0.0163$	1919.4	0.0843 at 6.349	6.3495	5.43895e -4
			no air			6.3157	5.4874e-4

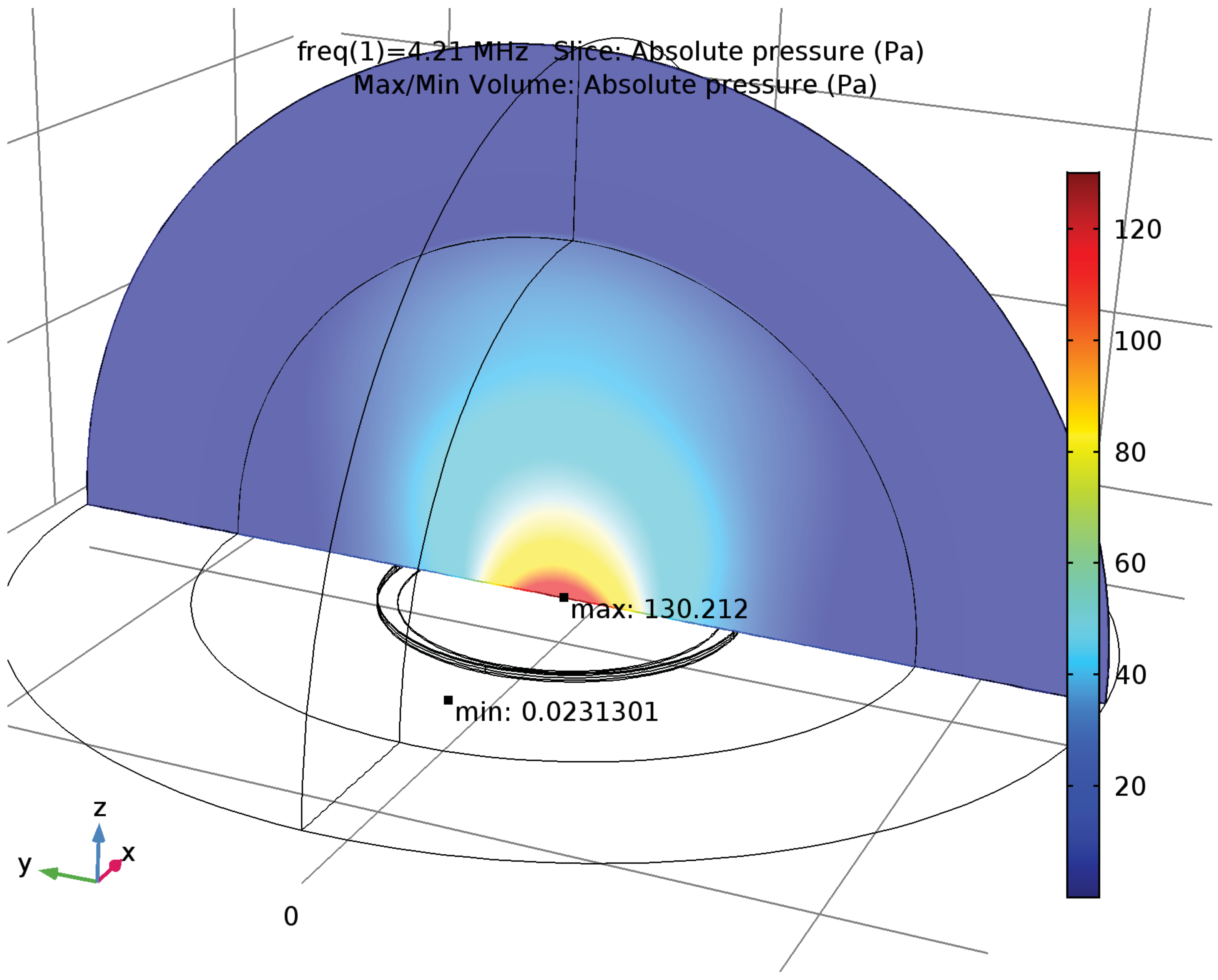

Figure 1: 3D simulation of the absolute pressure. The acoustic medium is air and PML boundary conditions were used.

Optimisation

To be examined as a sensor, a Stationary Study is used where a boundary load is defined over the top electrode. This way, an optimization of the top electrode is performed where ideally it must be in contact only with the positive or the negative charges produced by the piezoelectric material; see Figure 4.

When the device geometry is optimised so the device would work as actuator, the Stationary as well as Frequency domain studies are used. The outcomes that are taken into account are the static and the dynamic displacement as well as the resulted pressure and frequency; see the Table.

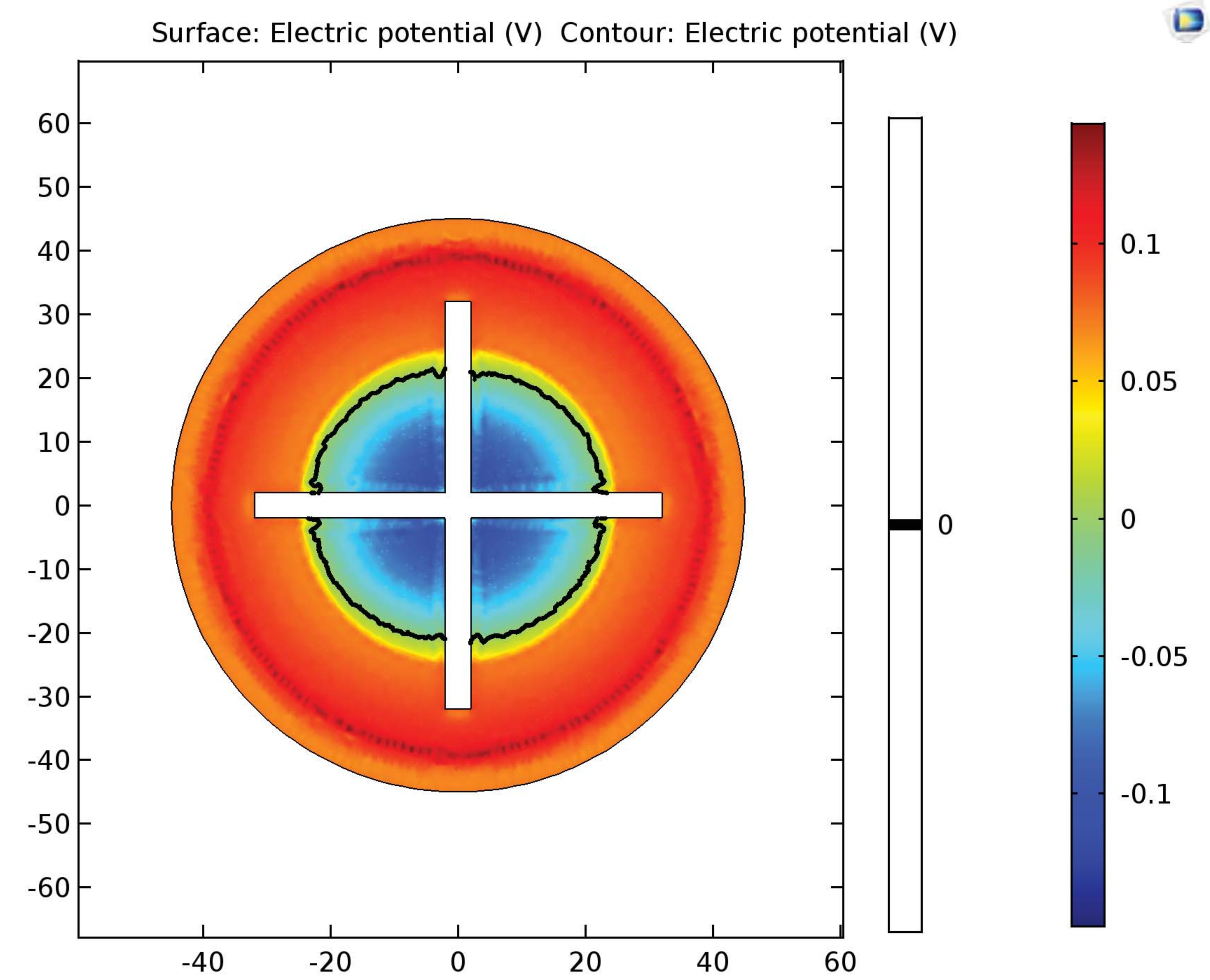

Figure 4: Electric potential distribution in a 2D intersection of the membrane.

References

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