Directional dependence of surface acoustic waves and induced acoustic streaming on 128˚ Y-Cut $LiNbO_3$: experiment vs. modeling

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Introduction: Microfluidic devices are finding wide spread application, but face certain challenges including the effect of decreased scale on fluid mechanical behavior. Acoustic streaming generated by a piezoelectric crystal is an attractive solution to pumping and streaming and may represent the only inertial phenomenon with bearing at this scale [1]. This study characterizes angular dependence of surface wave propagation for multiple orientations on 128˚ $LiNbO_3$ and relates this to acoustic streaming, or the flow field generated by the acoustic wave. As the shear vertical component of the surface wave couples most strongly with the liquid [2], one would expect that directions for which greater streaming velocities are measured will also show greater vertical displacement of the surface wave in simulations.

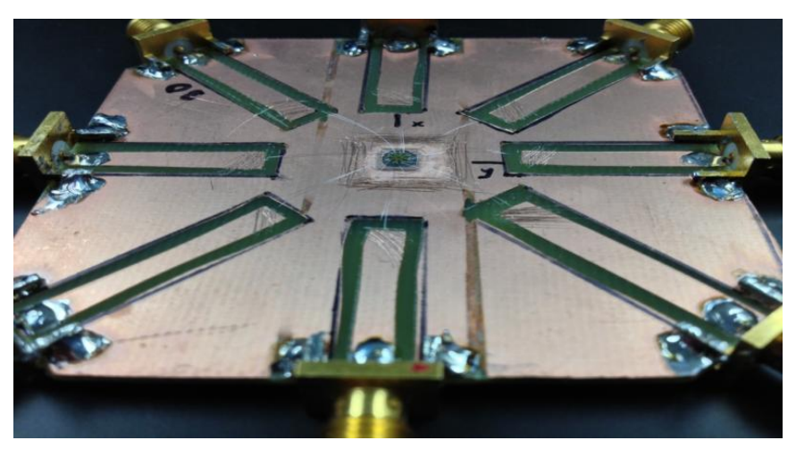
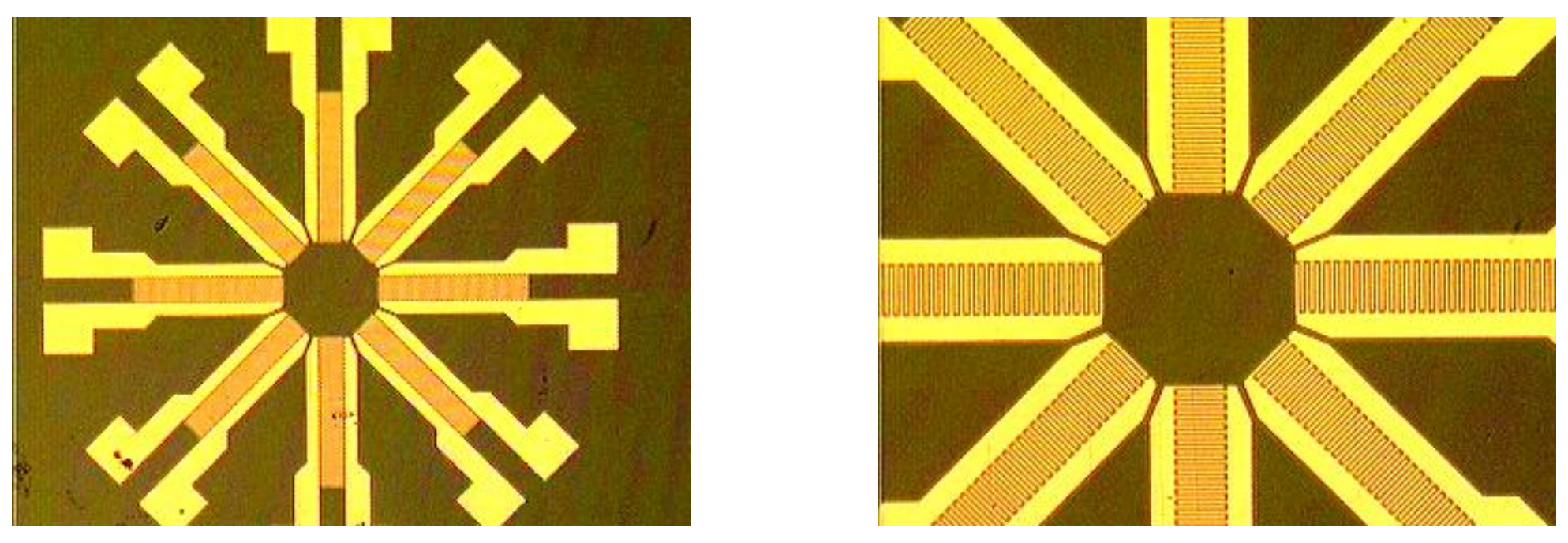
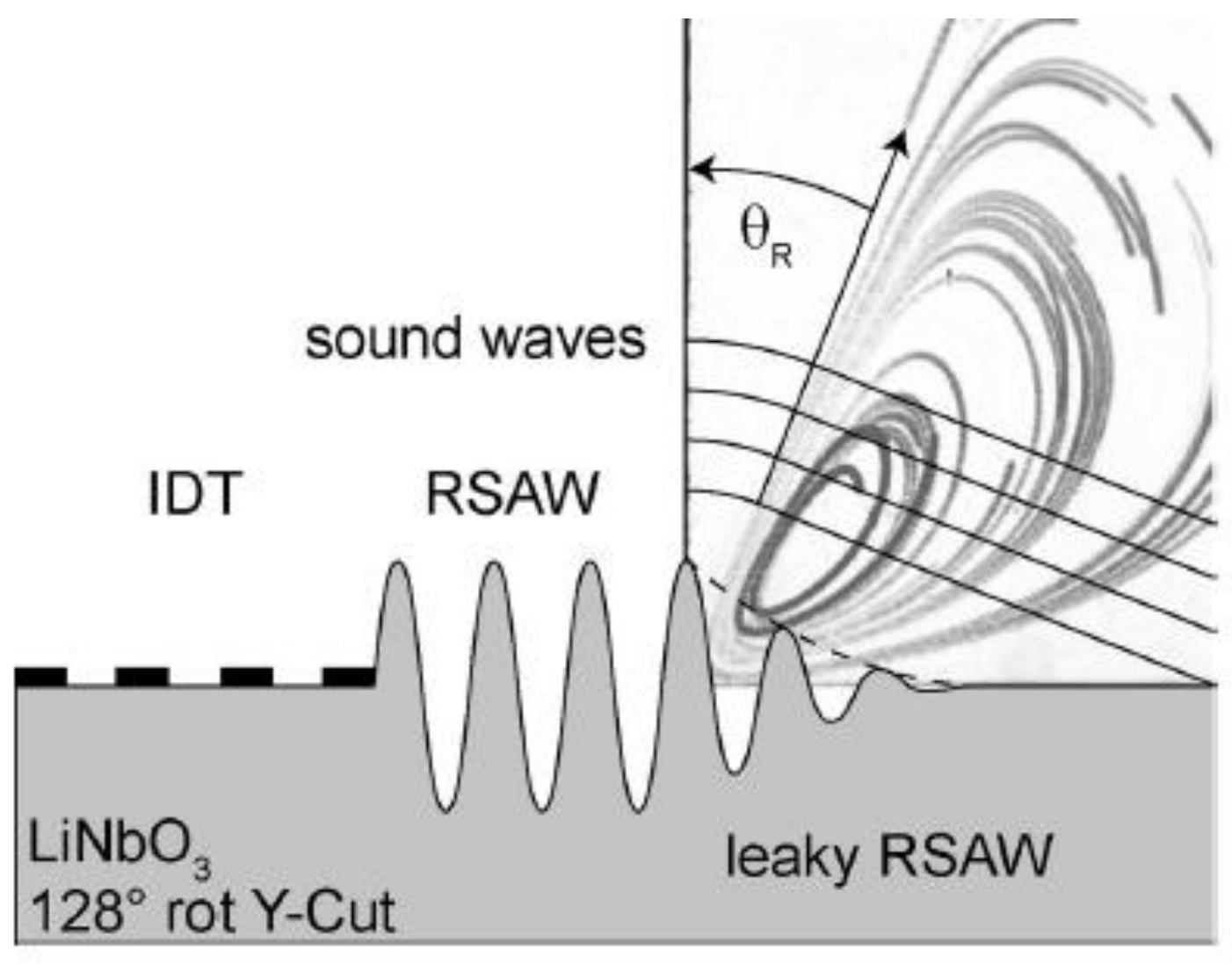


Figure 1. $LiNbO_3$ device in test package



Figures 2 & 3. Optical image of interdigitated electrodes on $LiNbO_3$



$$\Theta = \arcsin\left(v_{\text{liquid}} / v_{\text{surface wave}}\right)$$

Figure 4. Illustration of a surface acoustic attenuating its energy into liquid establishing a velocity field
(Image from [3])

Computational Methods: The model was developed using the piezoelectric module in COMSOL. The constitutive piezoelectric equations are:

$$T_{ij} = C_{ijkl}\,S_{kl} - e_{kij}\,E_k$$

$$D_i = e_{ikl}\,S_{kl} + \epsilon_{ik}\,E_k$$

Here C, e, and ε are the elasticity, piezoelectric coupling, and permittivity material constants respectively, represented by tensors. These values were input into COMSOL after being computed in Matlab using the Euler angles for the given material rotation, alternatively one could directly rotate the material in COMSOL. A perfectly matched layer (PML) is used instead of a fixed boundary condition at Γ_B as certain modes of propagation "leak" energy into the material. A PML acts as an absorbing boundary, allowing one to limit the size of the model by using this condition to replace a far off boundary not contributing reflections to the model. This serves to reduce the size of the geometry which needs to be meshed. The geometry was meshed to ensure a minimum of 12 elements per wavelength especially near the surface where displacements are greatest [4]. The solution was obtained in the frequency domain for a range of frequencies around the fundamental (Rayleigh) mode.

$u_L = u_R$
$v_L = v_R$
$w_L = w_R$
$V_L = V_R$
$u_F = u_B$

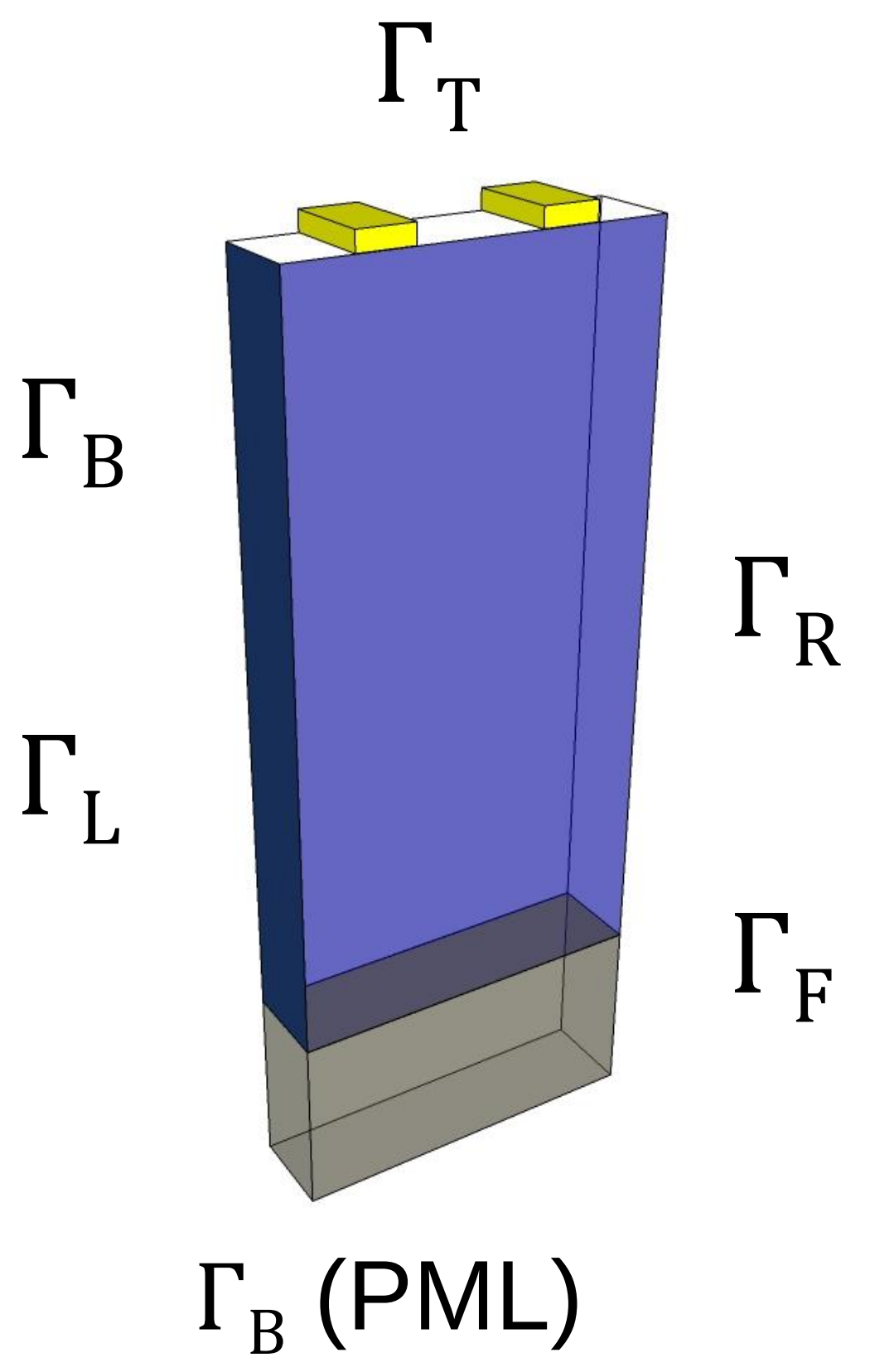


Figure 5. Representation of Geometry being modeled

Results: Strong (>99%) agreement was observed comparing experimentally determined resonances to FEM predictions (see Tab. 1). The fundamental resonant frequency was measured with a network analyzer. The simulated resonance was determined by extracting the complex admittance from the simulation data using the formula shown in Fig. 7. Further, streaming velocities were measured using a high speed camera and compared with simulated z-components of displacement, lending support to the hypothesis in the introduction -- the directions in which the greatest streaming were measured tended to show greater z displacements (see Fig. 8).

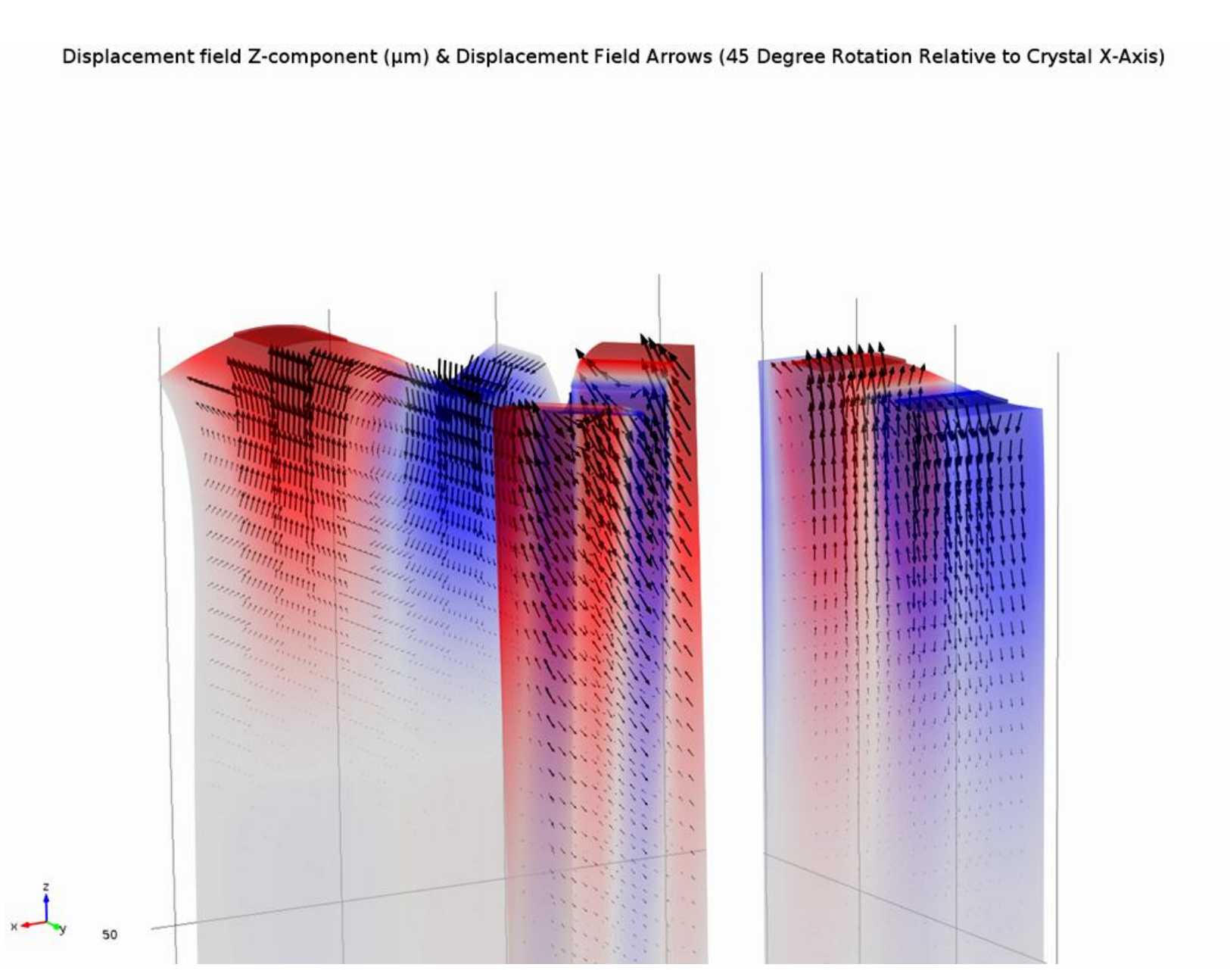


Figure 6. Vertical displacement component at 0, 45, and 90 (deg) rotations

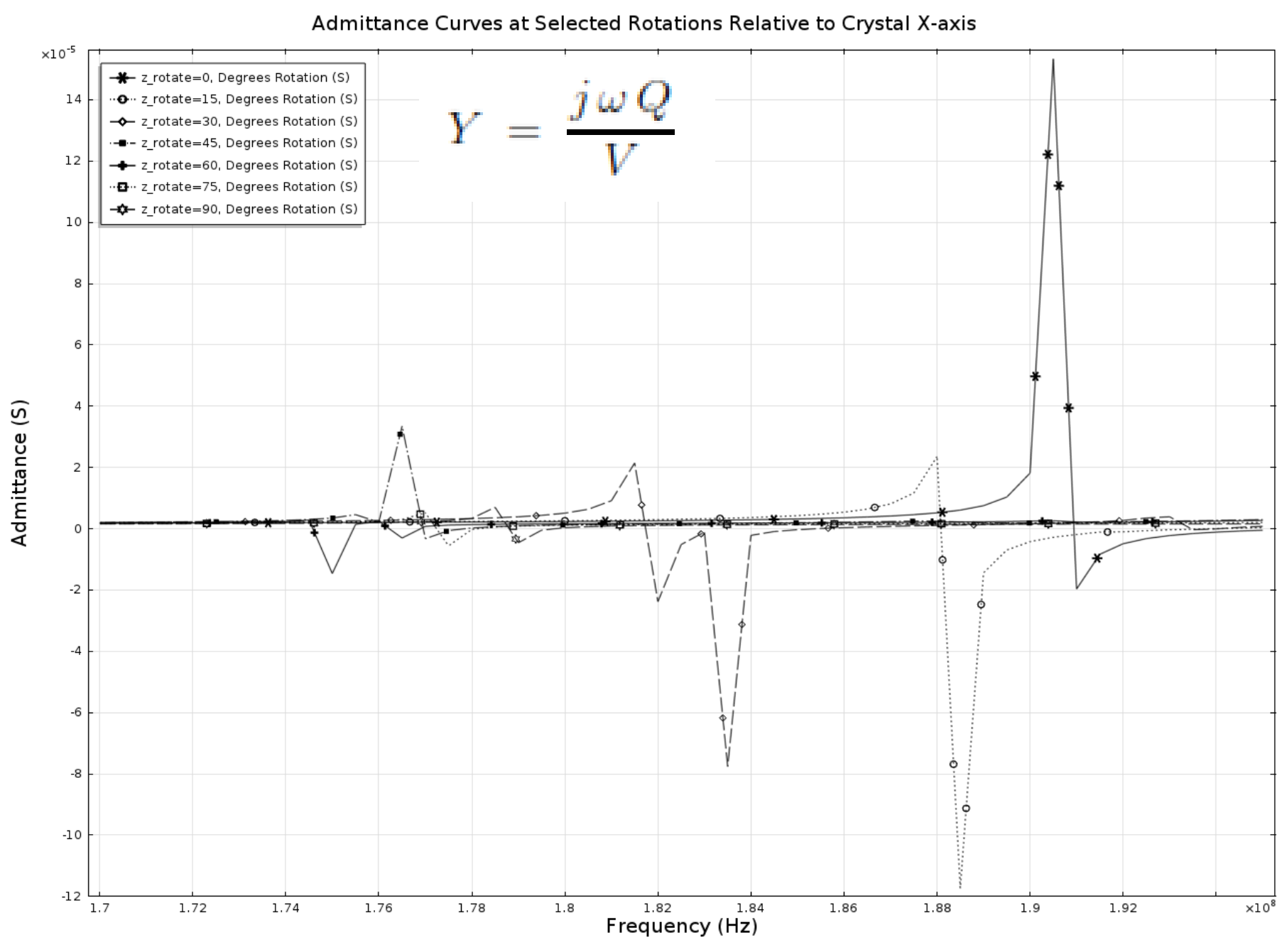


Figure 7. Admittance values extracted from simulation

Rotation from X-Direction (˚)	Experimental Resonance (MHz)	Simulated Resonance (MHz)	Relative Error (%)
0	192.25	190.5	.9
15	187.75	188.2	.24
30	*damaged	182.5	N/A
45	178.75	176.8	1.1
60	174.25	176.0	1.0
75	177.0	177.2	.1
90	178.75	178.7	.03

Table 1. Comparison of simulation to experiment

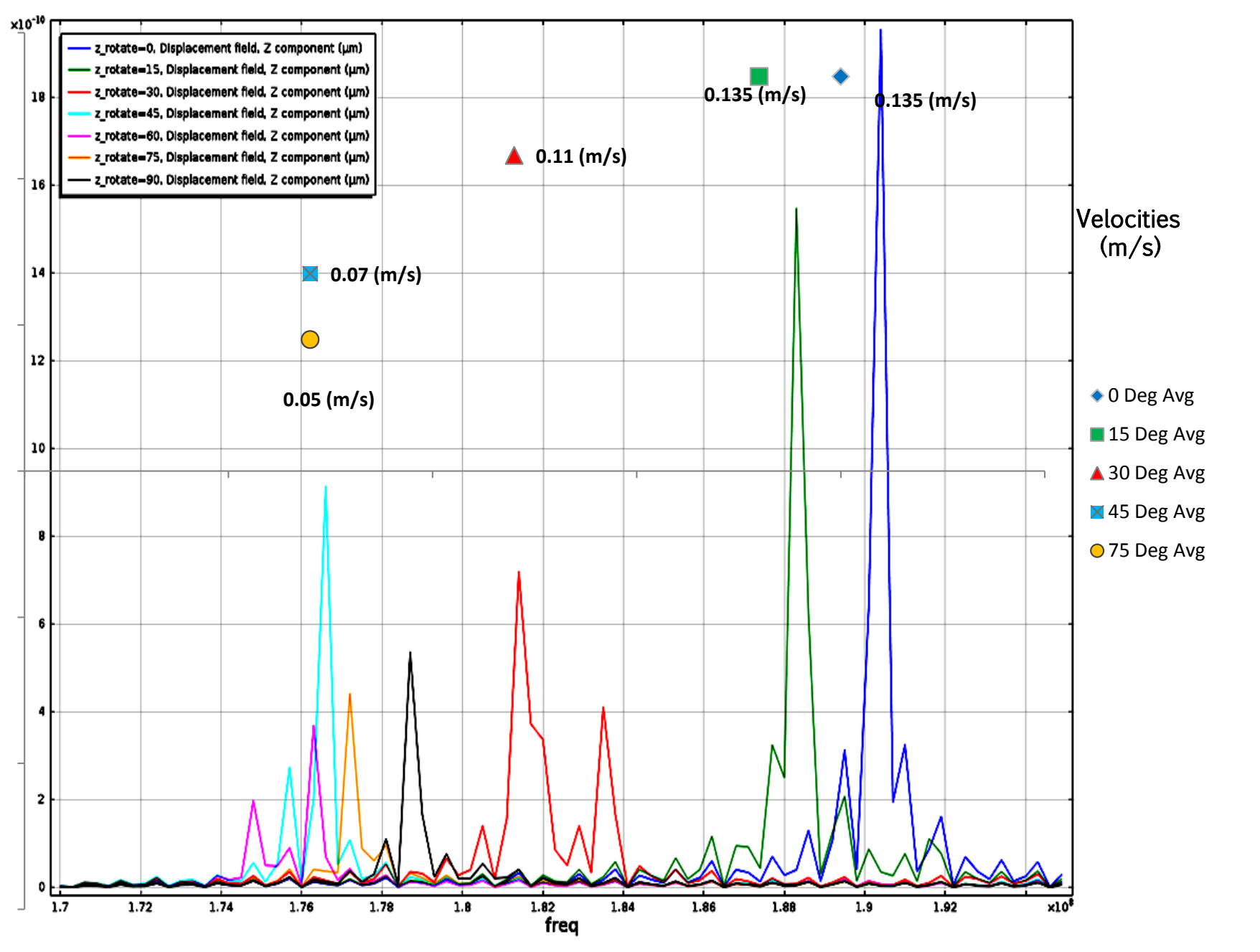


Figure 8. Maximum z disp. (simulated) vs. streaming velocity (measured)

Conclusions: COMSOL has been established to be a useful tool in guiding the design of test devices through comparison to experimental data. Future work includes the design of devices based on the results of these test devices/simulations, as well as simulations of alternative materials (i.e. AlN or ZnO thin films) to drive design of devices utilizing thin film depositions of these materials.

References:

1. Squires, T. & Quake, S., Microfluidics: Fluid physics at the nanoliter scale, Reviews of Modern Physics, 77, 977-1026 (2005)
2. Cheeke, D., Fundamentals and Applications of Ultrasonic Waves, 2002
3. Frommelt T. et. al, Flow Patterns and Transport in Rayleigh Surface Acoustic Wave Streaming, IEEE Trans. Ultra., 55, 2298-2305 (2008)
4. Kannan, T., FEM Analysis of SAW Resonators, Thesis (U. of Saskatchewan) (2006)

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