Finite Element Simulation of a Surface Acoustic Wave Driven Linear Motor

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Introduction

The piezoelectric materials have facilitated miniaturization of motors, and several mechanisms to construct ultrasonic motors have been reported [1], [2]. The advent of surface acoustic wave (SAW) motors led to improved resolution and high-power-density operation [3]. The function of SAW linear motor depends on the principle of friction drive provided by SAW propagating on a piezoelectric substrate [4].

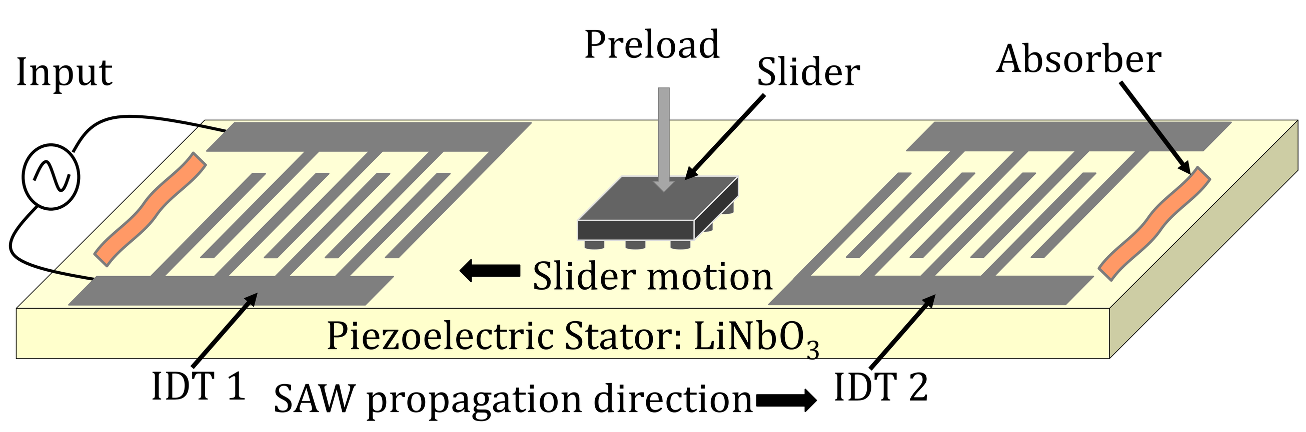

Figure 1. Piezoelectric SAW motor

- The motor is consists of a 128° rotated Y cut X propagating lithium niobate ($LiNbO_3$) or (LN) substrate used as stator.
- Aluminum (Al) electrodes are fabricated in the shape of comb structure called as interdigital transducers (IDTs) at both side ends as shown in Figure 1 [5].

Modeling and Simulation in COMSOL Multiphysics

The coupling of piezoelectric and solid mechanics physics in COMSOL Multiphysics is used for the simulation of the SAW motor. The FE simulation is performed in 3D plane geometry.

Geometry Settings

The dimensions in 3D plane geometry of SAW motor are as follows.

- Piezo-substrate: 400 µm (1 λ) × 2000 µm (5 λ) × 800 µm (2 λ) .
- IDT: 400 µm (1 λ) × 100 µm (¼ λ) × 0.2 µm.
- Slider: 200 µm × 100 µm × 100 µm having cylindrical projections of 40 µm diameter, 40 µm spacing and 4 µm height.

Parameters	Value	Units
Young's modulus of slider	215	GPa
Young's modulus of stator	173	GPa
Poisson's ratio of slider	0.29	-
Poisson's ratio of stator	0.33	-
Frequency	8.37	MHz

Table 1. Parameters used in simulation

Boundary Settings

- Stator (master) and slider (slave) form a contact pair.
- Bottom of the stator is fixed.
- Slider boundaries are kept free.
- Perfectly matched layers (PML) are added to the side edges of the stator to avoid reflections.
- Swept meshing is applied for all the domains.

Subdomain Settings

- The substrate used for the simulation is 128° rotated Y-cut X-propagating $LiNbO_3$.
- Slider is made of silicon.
- The stator is assigned as piezoelectric element.
- The IDTs and slider are declared as linear element.
- The IDTs are assigned with electric elements to apply input power.

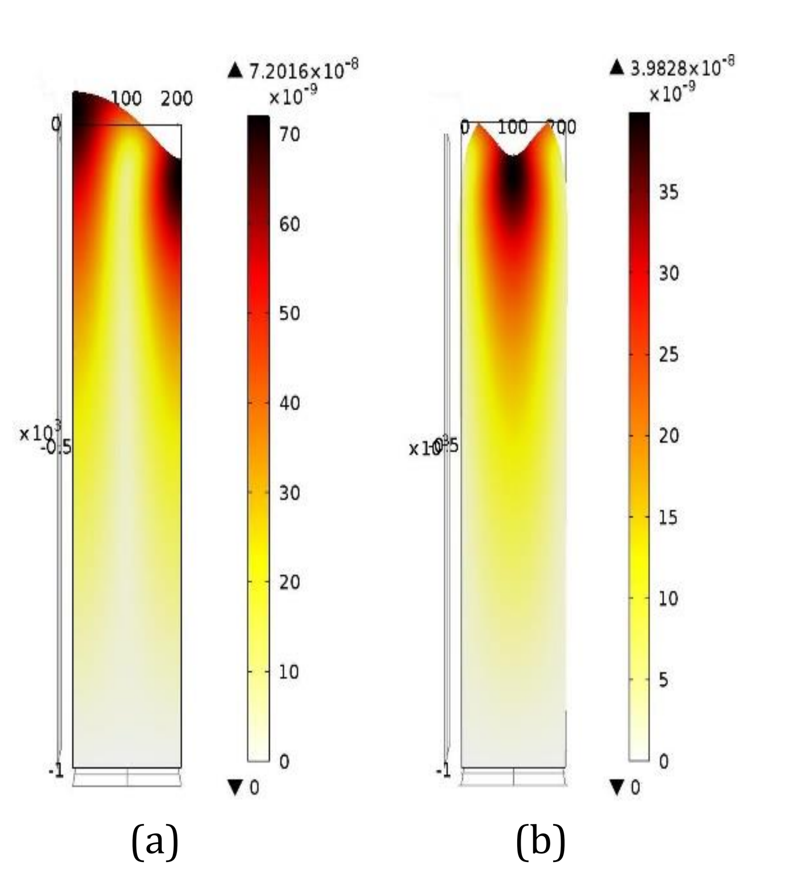

Figure 2. Displacement profile (a) resonance and (b) anti-resonance of resonator

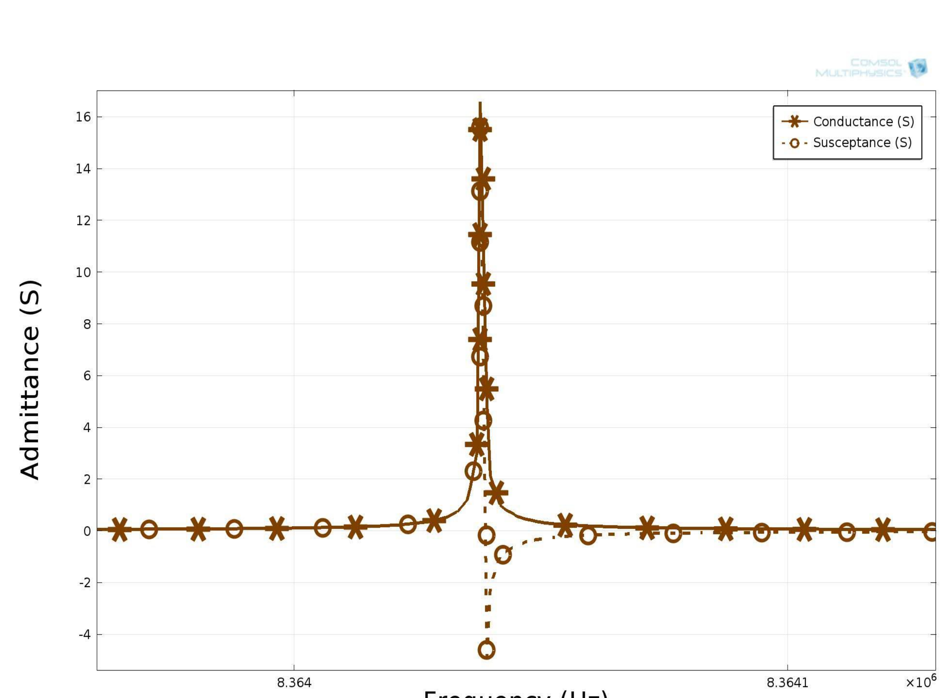

Figure 3. Admittance plot for resonator

Results

- The slider makes tight contact with the stator with the application of preload from the top. The Rayleigh wave makes a frictional contact at the bottom surface of the slider and displaces the slider as shown in Figure 5.

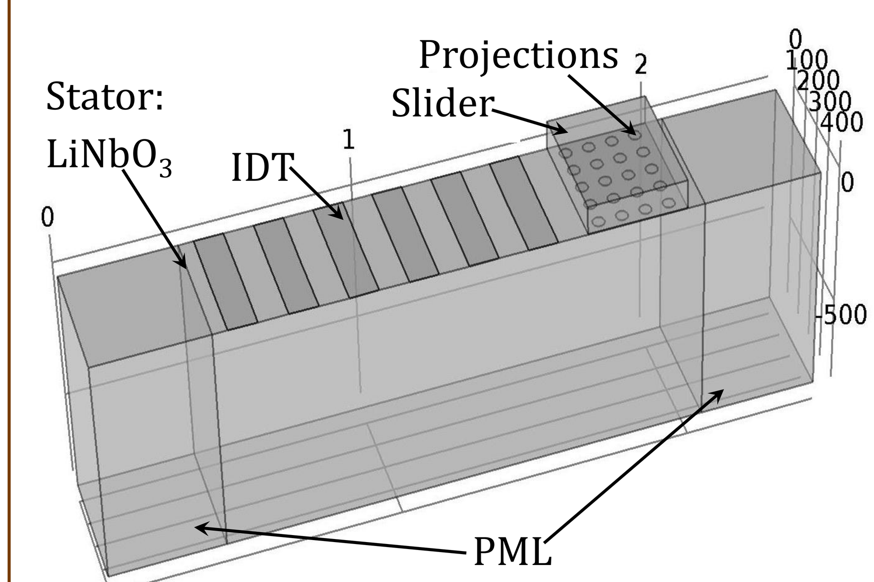

Figure 4. Surface acoustic wave motor structure made for simulation

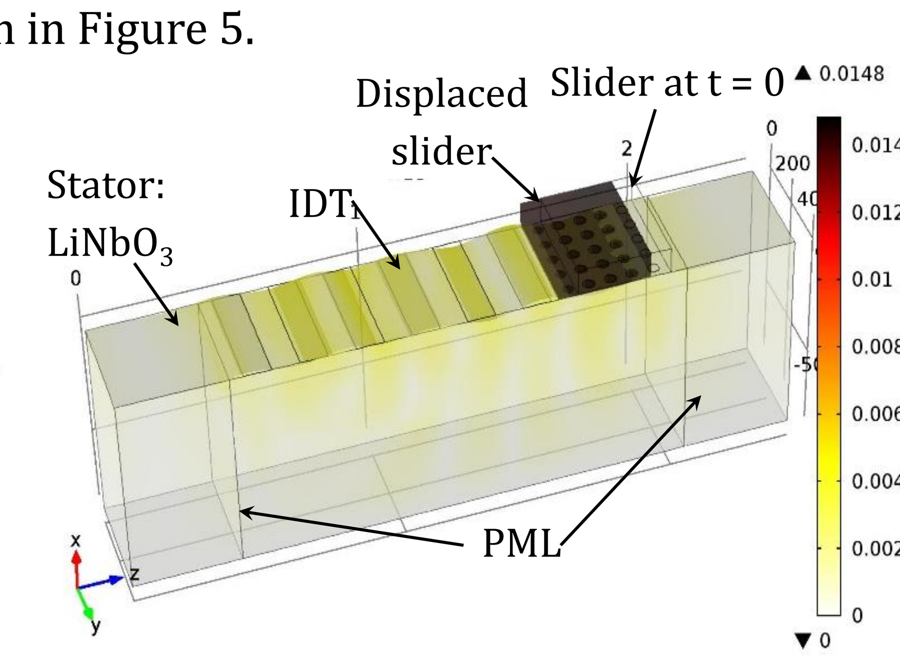

Figure 5. Displacement profile showing surface vibrations and slider movement

- At the crest of the wave the slider sticks with the wave and frictional force acting on the slider moves it in the direction of motion of the stator surface.
- At the trough of the wave the slider makes another contact with the wave but the force transmitted to the slider is not significant.
- The rest of the time the slider is not pushed as it is not in contact with the wave and the state is called as slip condition.

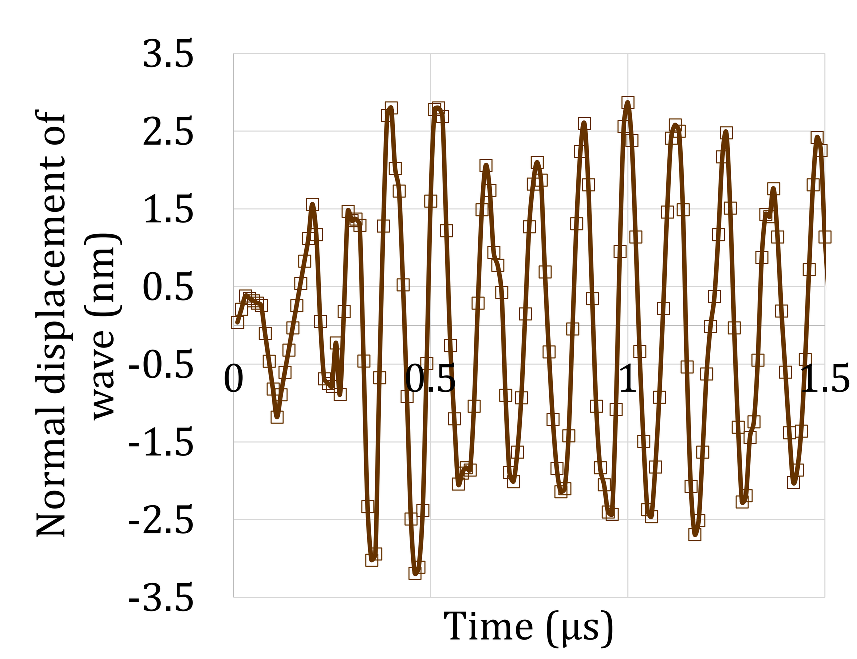

Figure 6. Normal displacement of wave

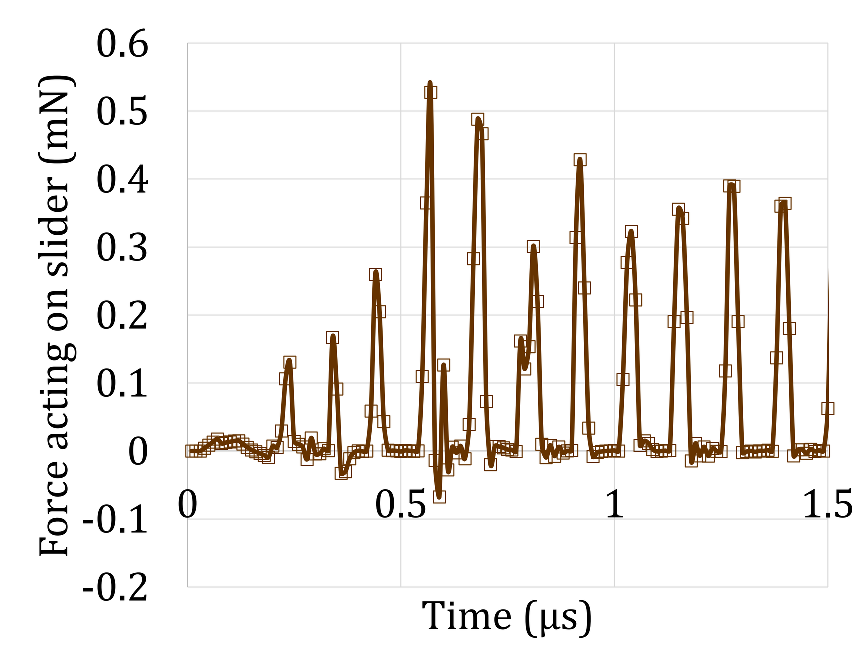

Figure 7. Tangential force on slider

- The normal component of the displacement of a point on surface of the stator is shown in Figure 6.
- The tangential force acting on the slider through friction drive is shown in Figure 7.
- The displacement and velocity of the slider due to frictional force is as shown in Figure 8 and Figure 9 respectively.

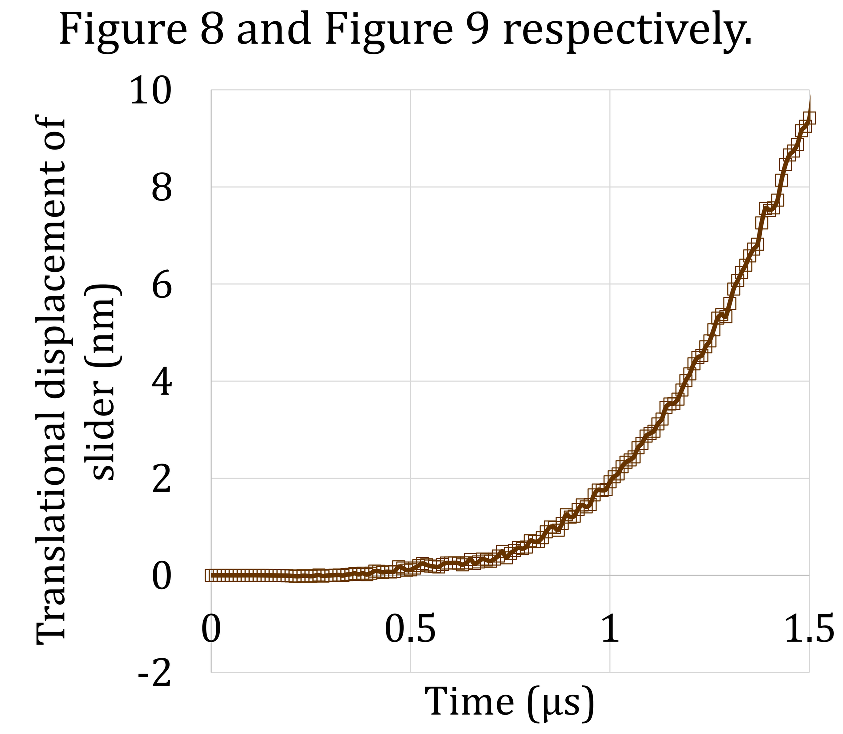

Figure 8. Translational motion of the slider

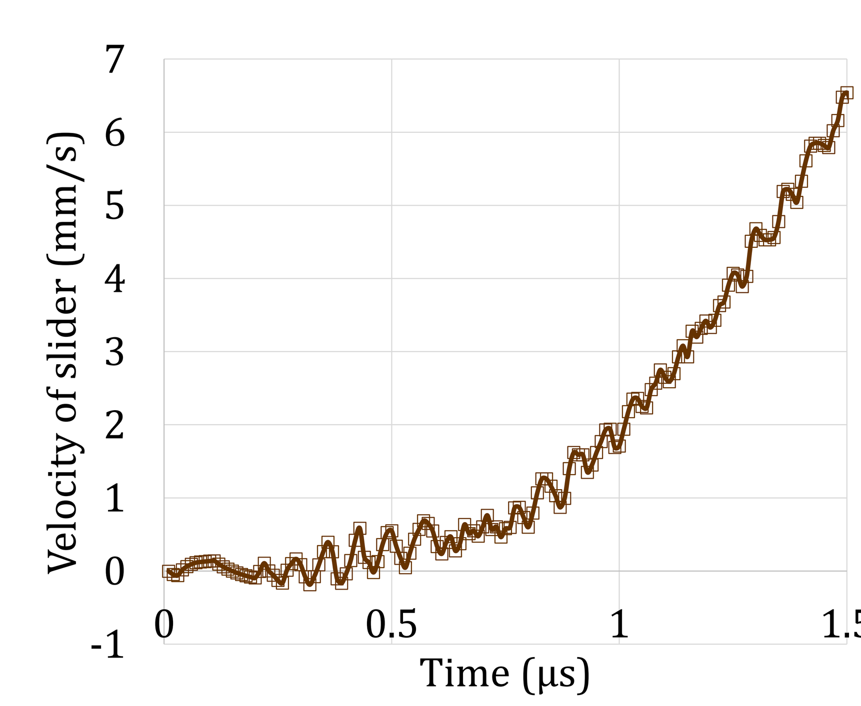

Figure 9. Velocity of the slider

Conclusion

- A SAW motor is simulated in COMSOL Multiphysics.
- The translational force acting on the slider due to propagation of Rayleigh wave under the slider is observed.
- The displacement of the slider in normal and translational directions are observed.

References

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