Finite Element Simulation of Love Wave based SAW Delay Line using COMSOL Multiphysics

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Introduction: The paper presents 3D FE simulation of Love wave based Surface acoustic wave (SAW) delay line using COMSOL Multiphysics. A Love wave is a type of shear-horizontally polarized elastic wave that can be produced in a *leaky SAW* device when an overlayer with an acoustic shear velocity less than that in the bulk is deposited over the propagation path [1]. In comparison to Rayleigh SAW devices, Love wave due to its shear-horizontal nature, exhibit very less attenuation in liquids and is very promising for biosensor design [2].

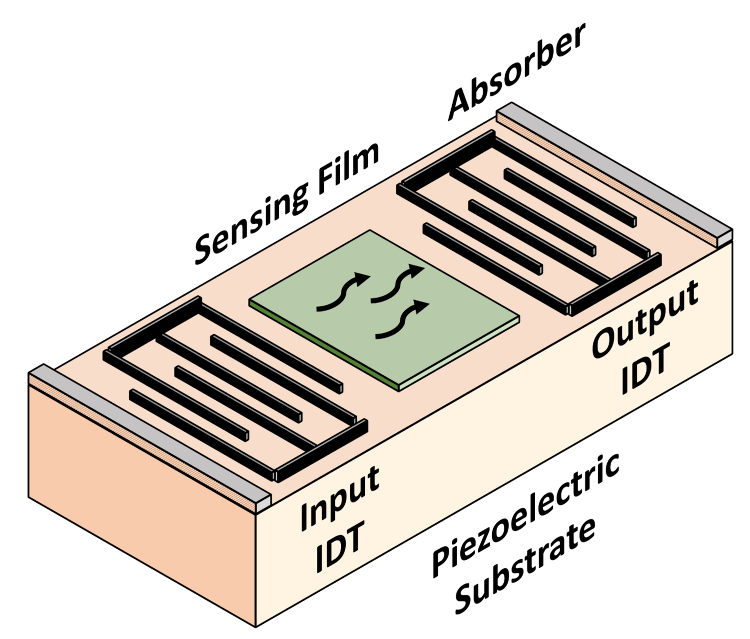

Figure 1. Basic SAW delay line as sensor.

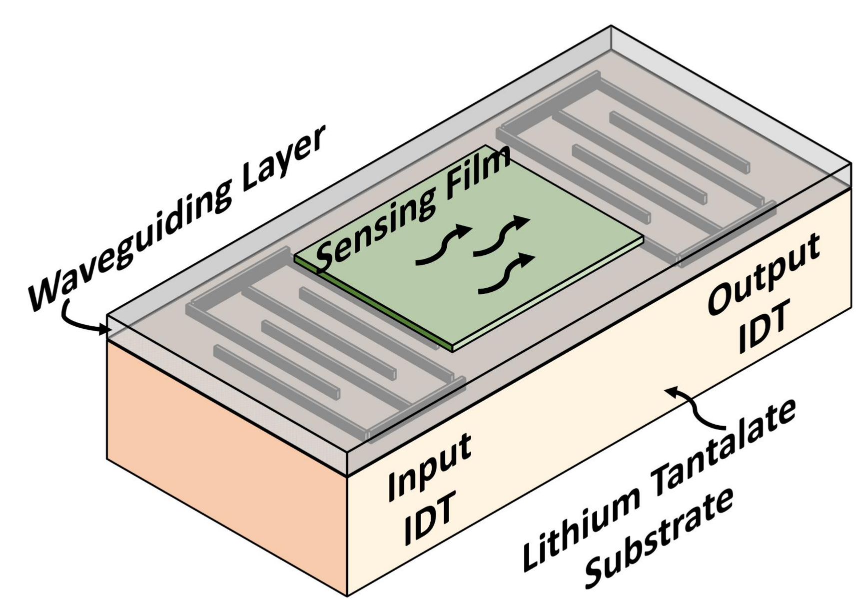

Figure 2. Love wave delay line as sensor.

Simulation Methodology: The 3D geometry used for simulation is shown in Figure 3. The device consists of a 36°–YX Lithium Tantalate substrate covered with 4.7 μm thick SiO_2 waveguide layer. Periodic boundary conditions are kept along *z* axis so that the IDT aperture is infinite. Critical damping is implemented at the either ends of the device so that there are no reflections from the edges. An impulse signal is applied at the input IDT for calculation of insertion loss of the device while a sinusoidal input is applied for calculating phase shift of signal. Mass loading is simulated by placing a thin 200 nm PMMA layer over the mass loading region.

λ = Wavelength of SAW (12 μm)

p = IDT electrode width = $\lambda/4$

D = Distance between input and output IDT electrode

L_m = Length of mass loading central region

L = Center to center distance between IDTs

A_{dm} = Mass proportional damping coefficient

B_{dk} = Stiffness proportional damping coefficient

$$\xi_r = \frac{A_{dm} + B_{dk}\omega^2}{2\omega} = \text{Damping ratio}$$

$$S_{m\phi} = \lim_{\Delta m \to 0} \frac{1}{kD}\frac{\Delta\phi}{\Delta m} = \text{Phase mass sensitivity in } (\text{m}^2/\text{kg})$$

$$S_m = \left(\frac{D}{L}\right) S_{m\phi} = \text{Frequency mass sensitivity in } (\text{m}^2/\text{kg})$$

$$IL(dB) = 20\log\left(\left|\frac{V_{out}}{V_{in}}\right|\right) \text{ (Insertion loss of device in dB)}$$

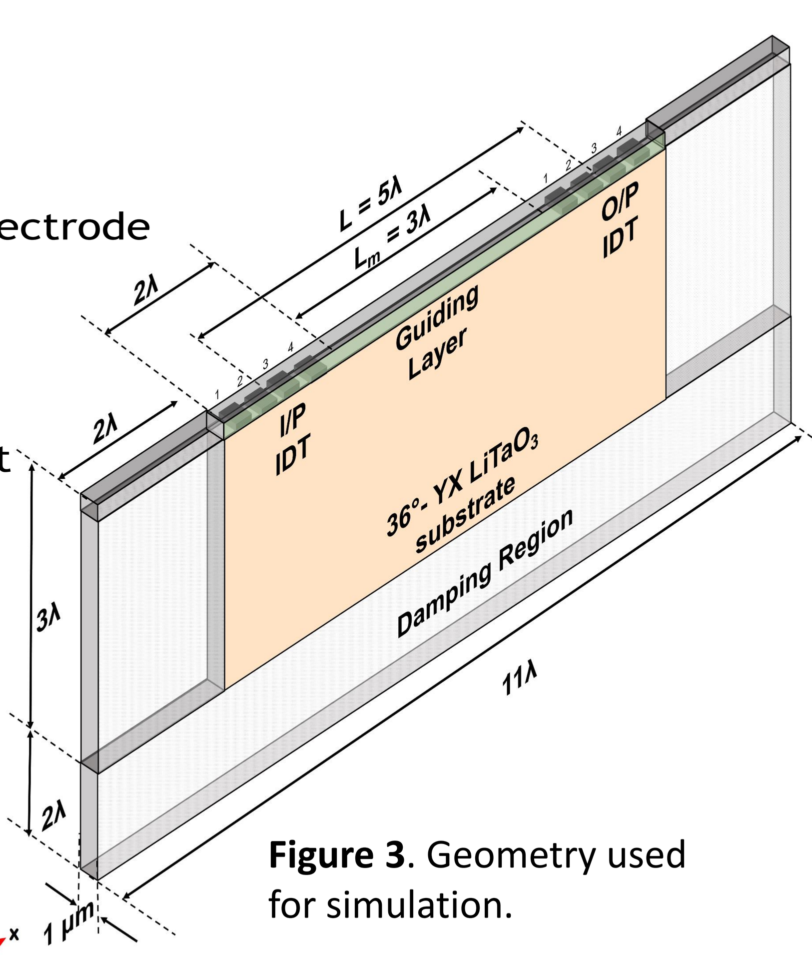

Figure 3. Geometry used for simulation.

Time Response

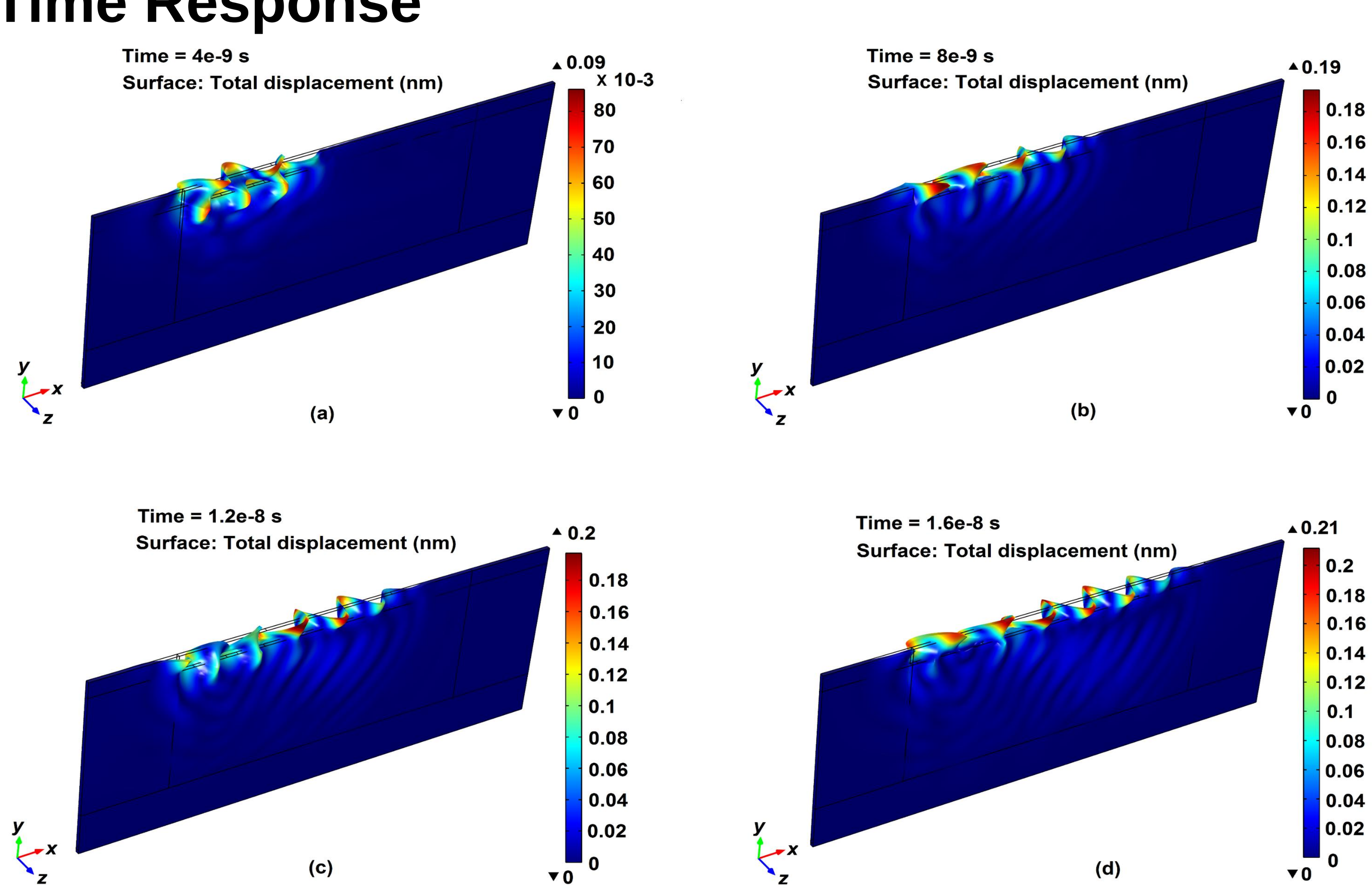

Figure 4. Snapshots of time response of delay line at (a) 4 ns (b) 8 ns (c) 12 ns and (d) 16 ns.

Results: The time response and displacement plots confirm the shear horizontal nature of Love wave. A phase velocity of 3750 m/s is obtained for the generated Love wave.

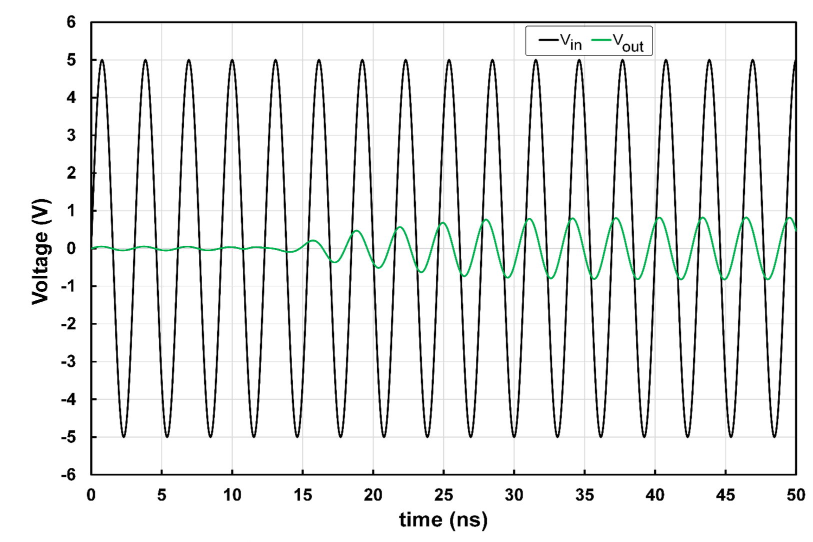

Figure 5. I/P and O/P voltage with time.

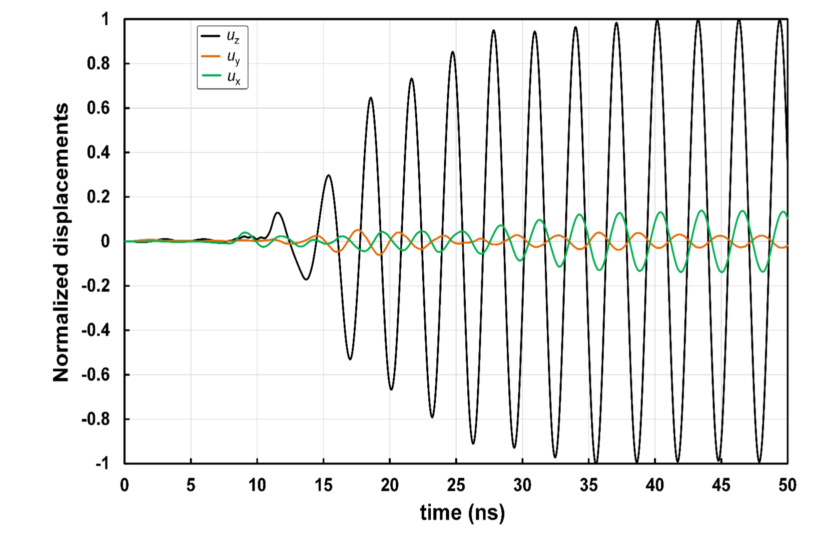

Figure 6. Displacement components at the O/P IDT.

The calculated insertion loss of device is -32.2 dB at 326.9 MHz.

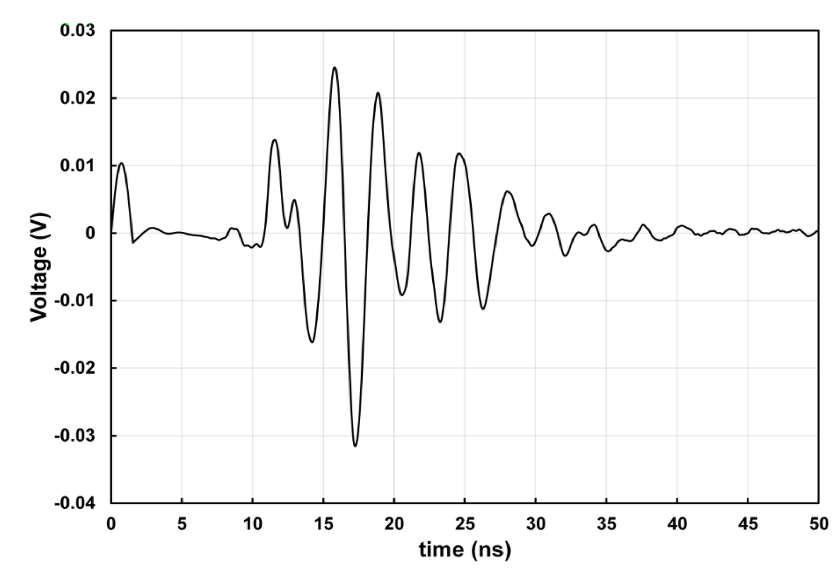

Figure 7. Impulse response.

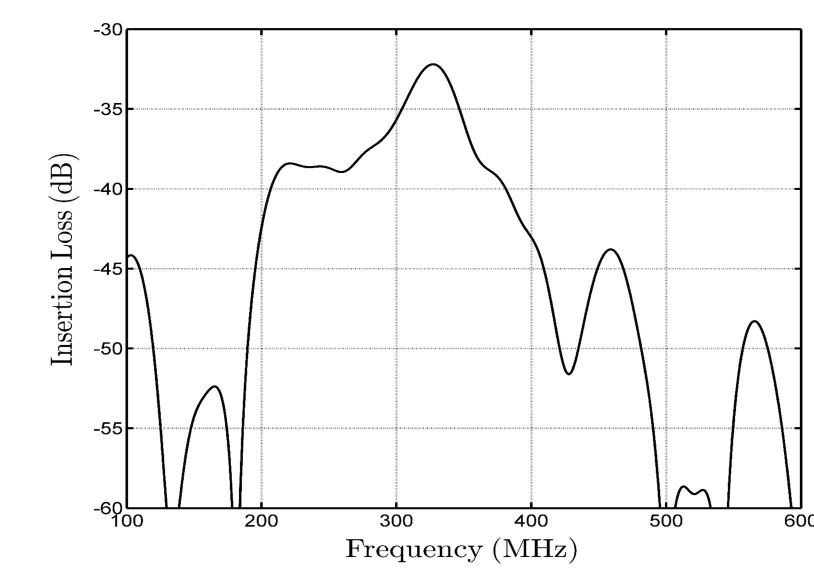

Figure 8. Insertion loss of Love wave delay line.

The device gives a phase mass sensitivity of 83.22 m^2/kg and frequency mass sensitivity of 54.09 m^2/kg which is consistent with previously reported values [3].

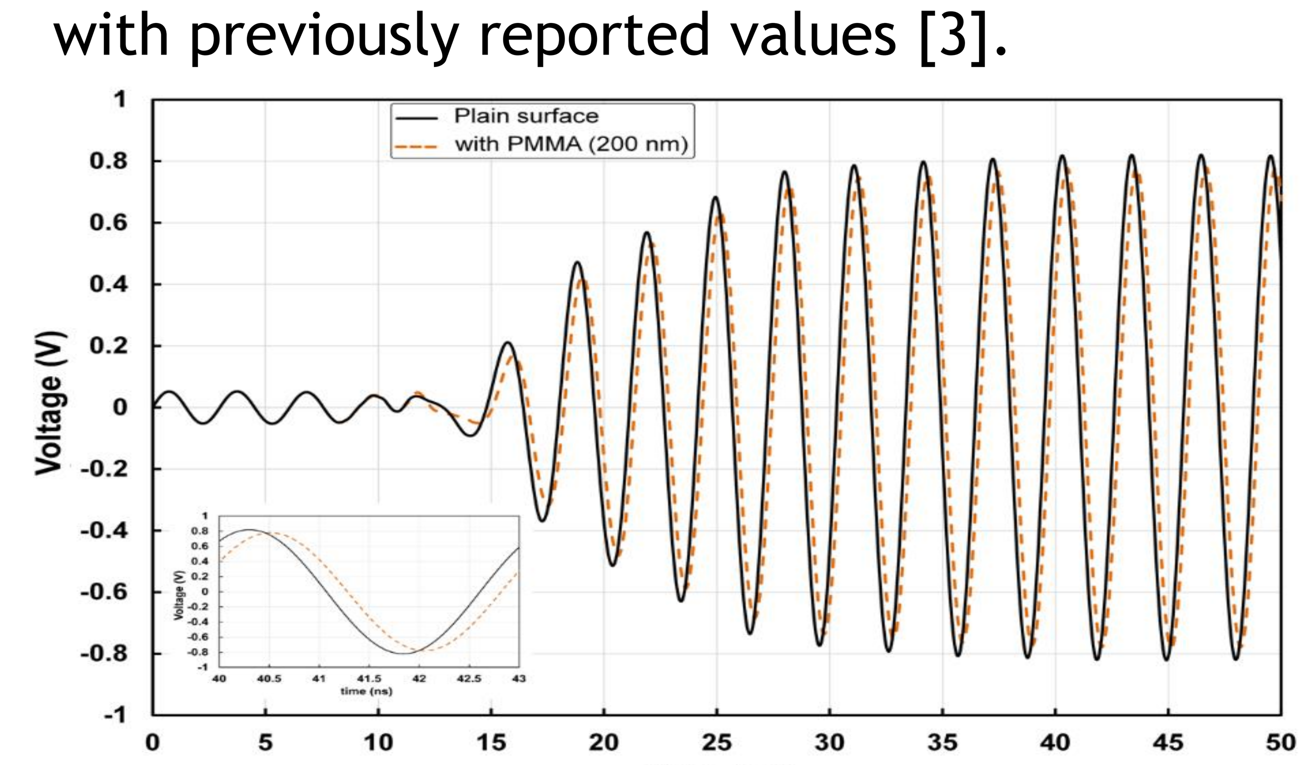

Figure 9. Phase shift due to mass loading. Plot of output voltage versus time for the plain surface and 200 nm thick PMMA loaded surface. Inset shows the time delay between two waveforms.

PMMA Height (nm)	Incremental mass per unit area Δm (kg/m^2)	Time delay Δt (ns)	Phase shift Δφ(rad)
200	2.36 X 10^{-4}	0.2099	0.4286
210	2.48 X 10^{-4}	0.2196	0.4484
220	2.60 X 10^{-4}	0.2295	0.4686
230	2.71 X 10^{-4}	0.2384	0.4868
240	2.83 X 10^{-4}	0.2496	0.5097
250	2.95 X 10^{-4}	0.2586	0.5281

Table 1. Time delay and phase shift obtained upon loading the SAW Delay line with PMMA layer of different heights .

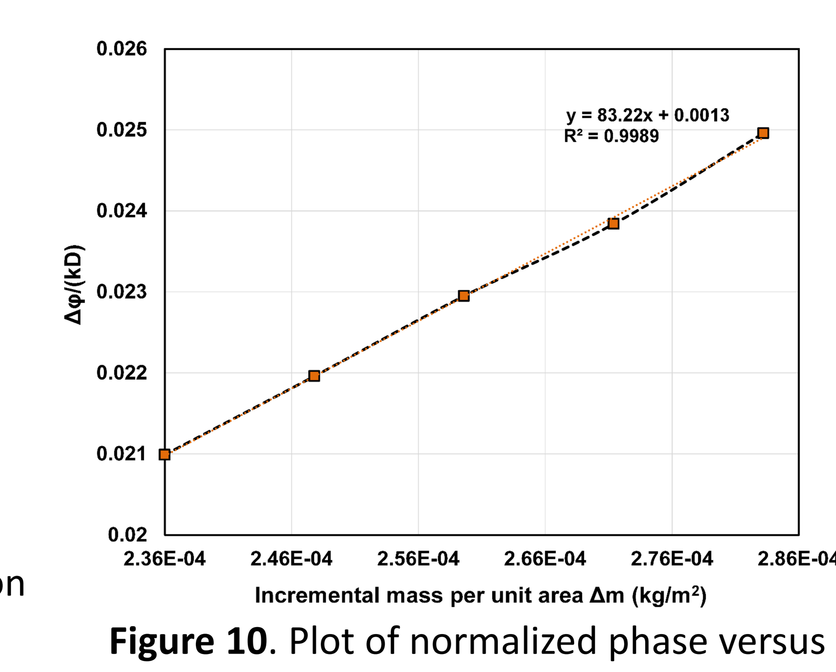

Figure 10. Plot of normalized phase versus incremental mass per unit area .

Conclusions: We perform the time response study to calculate the normalized displacements, output voltage, insertion loss and mass sensitivity of the Love wave device. Typically delay line simulation requires large geometry and memory usage but using periodic boundary conditions in COMSOL aids to keep the geometry small. Simulation of SAW devices using COMSOL can help to obtain the device characteristics prior to actual fabrication.

References

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