COMSOL Multi-Physics Applied to MEMS Simulation and Design

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AlN based LAMB WAVE pressure sensor

AlN based LAMB WAVE pressure sensor

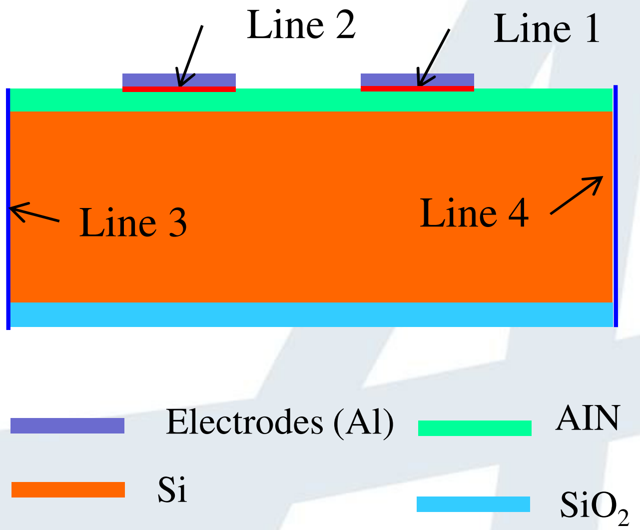
The simulation is to investigate the nature characteristics of a novel ruggedized high temperature pressure sensor operating in lateral field exited (LFE) Lamb wave mode, which can be operated in harsh environment such as oil & gas exploration, automobile and aeronautic applications.

The comb-like structure electrodes on top of aluminum nitride (AlN) were used to generate the wave. A Membrane was fabricated on SOI wafer with 10 µm, 30 µm and 50 µm thick silicon device layer.

The phase velocity dispersive curve of the Lamb wave under different Si thickness (Bulk, 10 µm, 30 µm and 50 µm) are simulated. Compared with the phase velocity dispersion curves of Lamb wave in pure AlN/Al plate that has been reported before, higher order Lamb wave mode are observed with a non-dispersive behavior over a wide range (from 10 to 50 µm Si thickness) comparable to S_0 mode for thin plates.

Simulation approach

Physics employed: Piezoelectric Devices (pzd)



Condition setting:

Piezoelectric material model 1	AIN	Periodic Condition 1	Line 3,4
Free 1	default	Zero charge 1	default
Initial values 1	default	Electrical material model 1	Al, Si, SiO_2
Ground 1	Line 1	Global Definitions: Parameters	Lambda: 20 µm
Electric potential 1	Line 2, V_0=1 V		
Linear Elastic Material Model 1	Al, Si, SiO_2		

Mesh setting:

Sequence type: Physics-controlled mesh

Element size: Normal

Study 1:

Step: Frequency Domain

Frequency: 200 MHz-1000 MHz

Simulation: different thickness of AIN to lambda ratio (0.05-0.4) vs phase velocity have been investigated on different structures with underneath Si layer of thickness 10 µm, 30 µm, 50 µm, bulk Si and pure AIN

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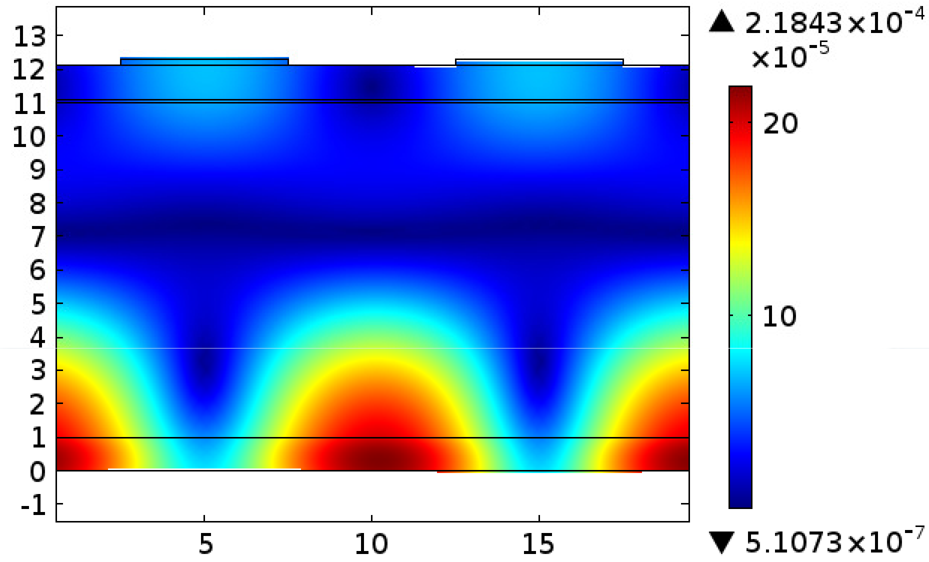
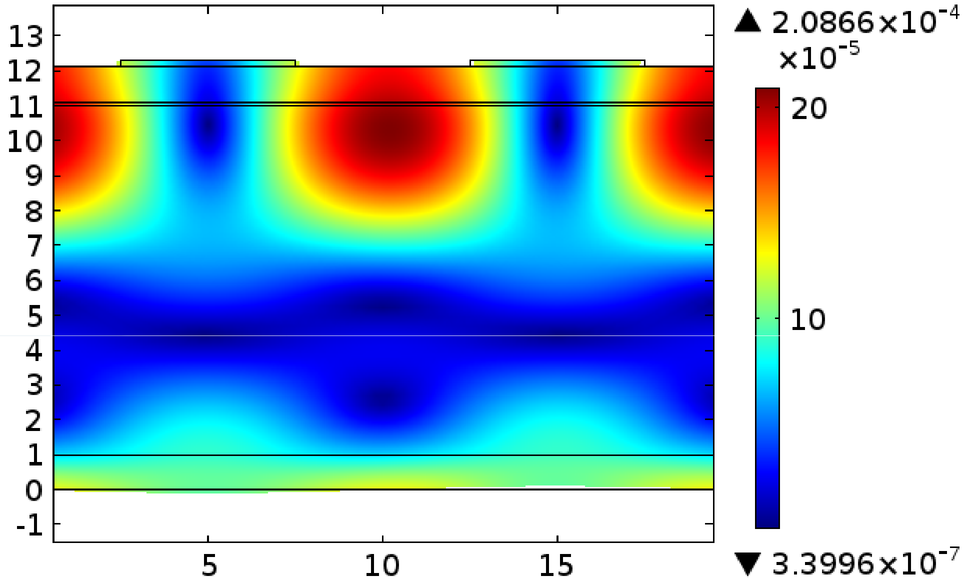
Simulation results

Si thickness of 10 µm:



442.12 MHz

S_0 wave

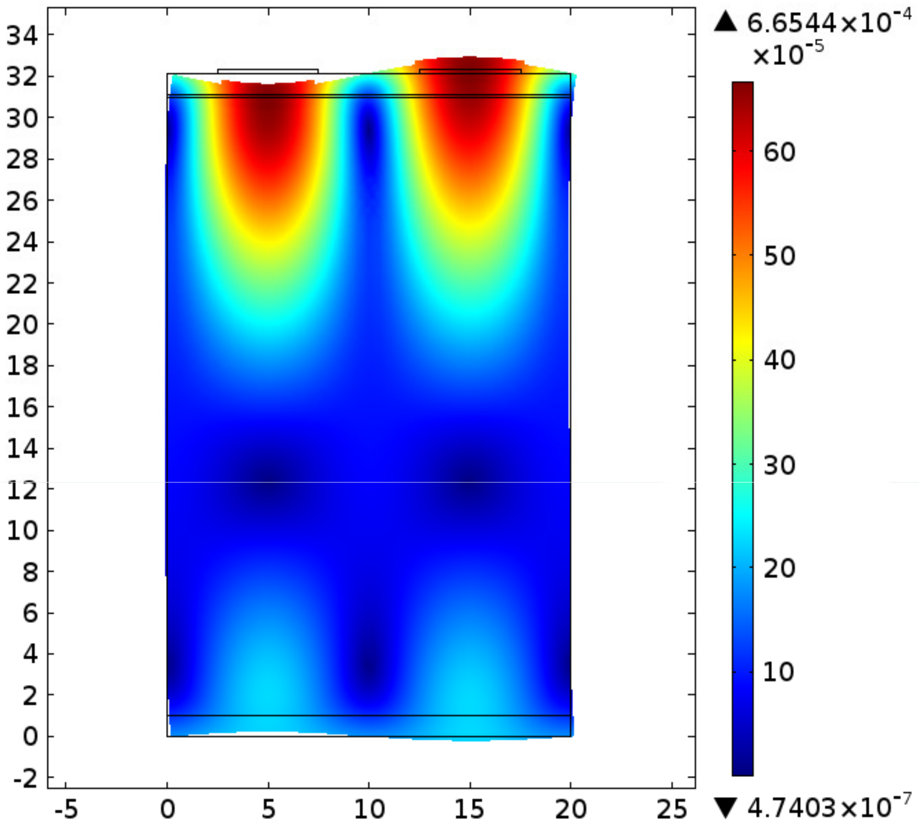


502.98 MHz

Lamb wave

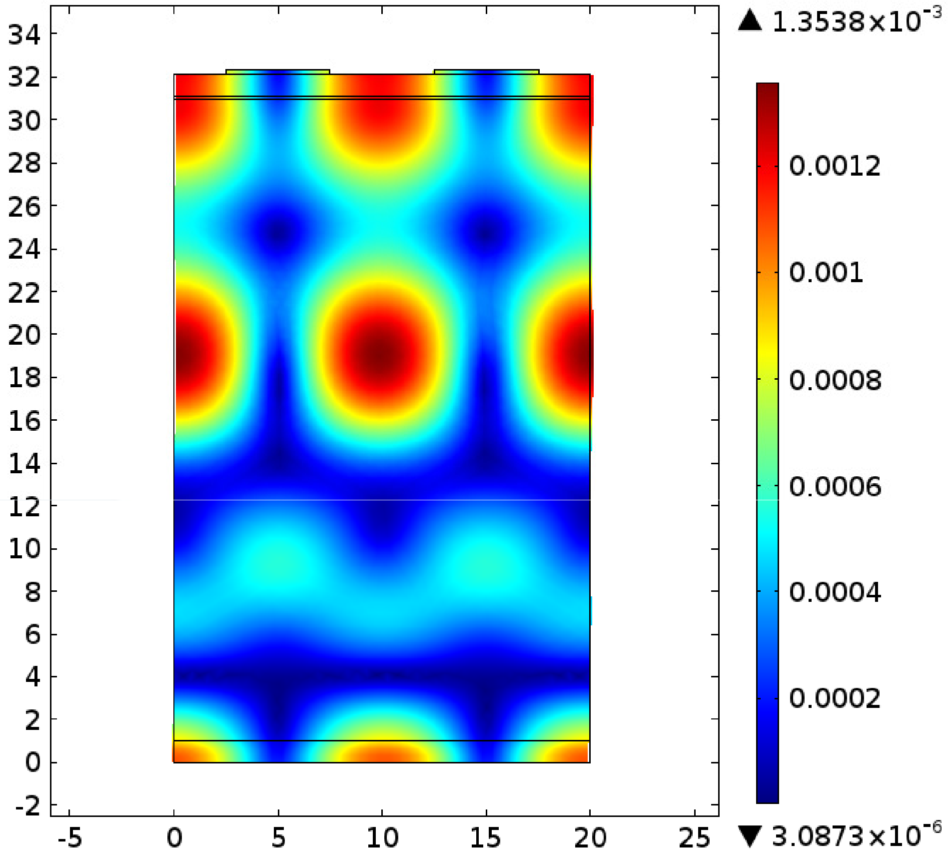
Simulation results

Si thickness of 30 µm:



247.80 MHz

S_0 wave

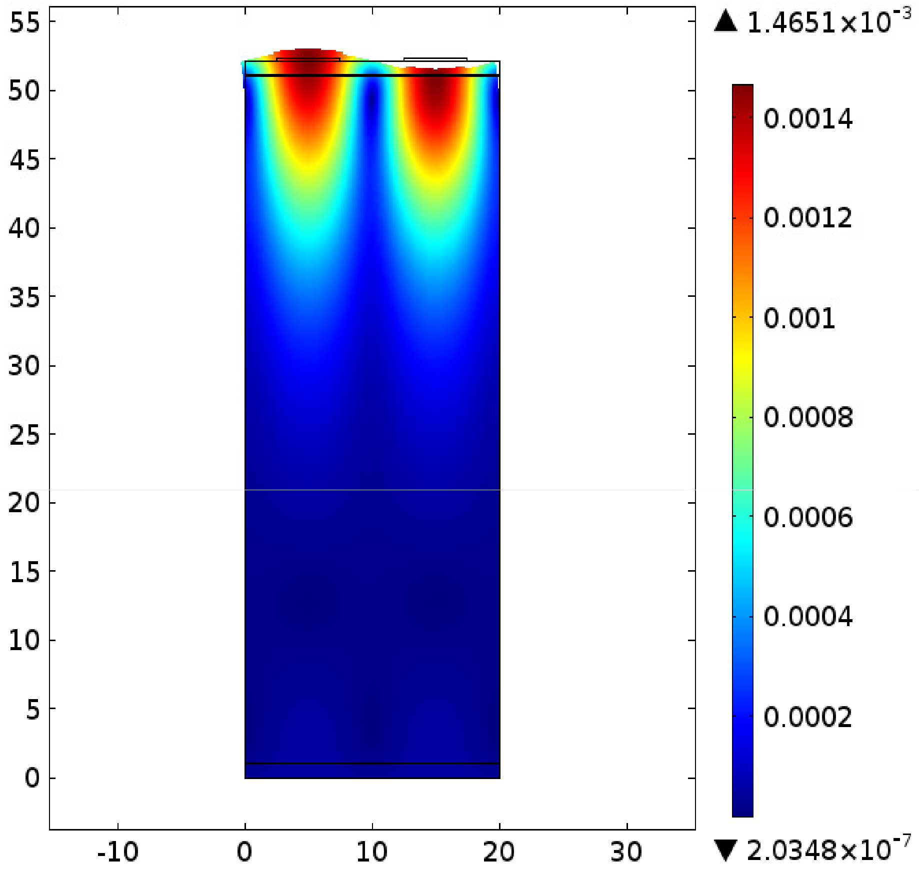


503.15 MHz

Lamb wave

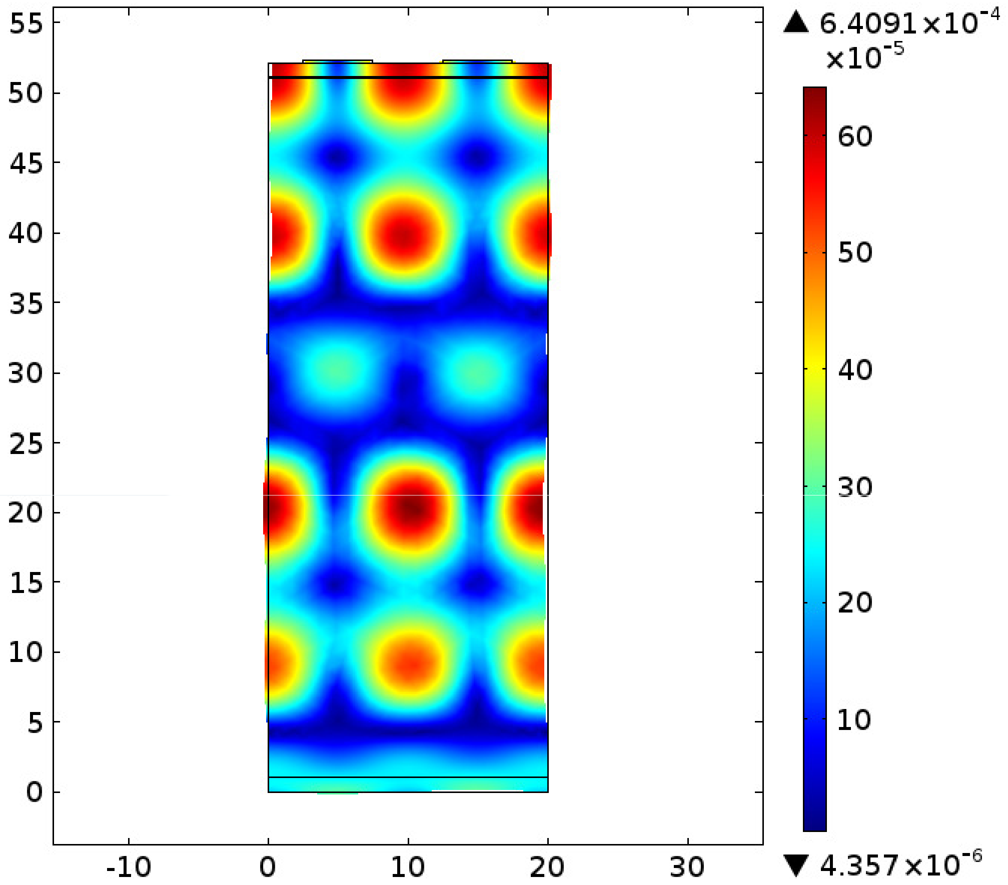
Simulation results

Si thickness of 50 µm:



246.41MHz

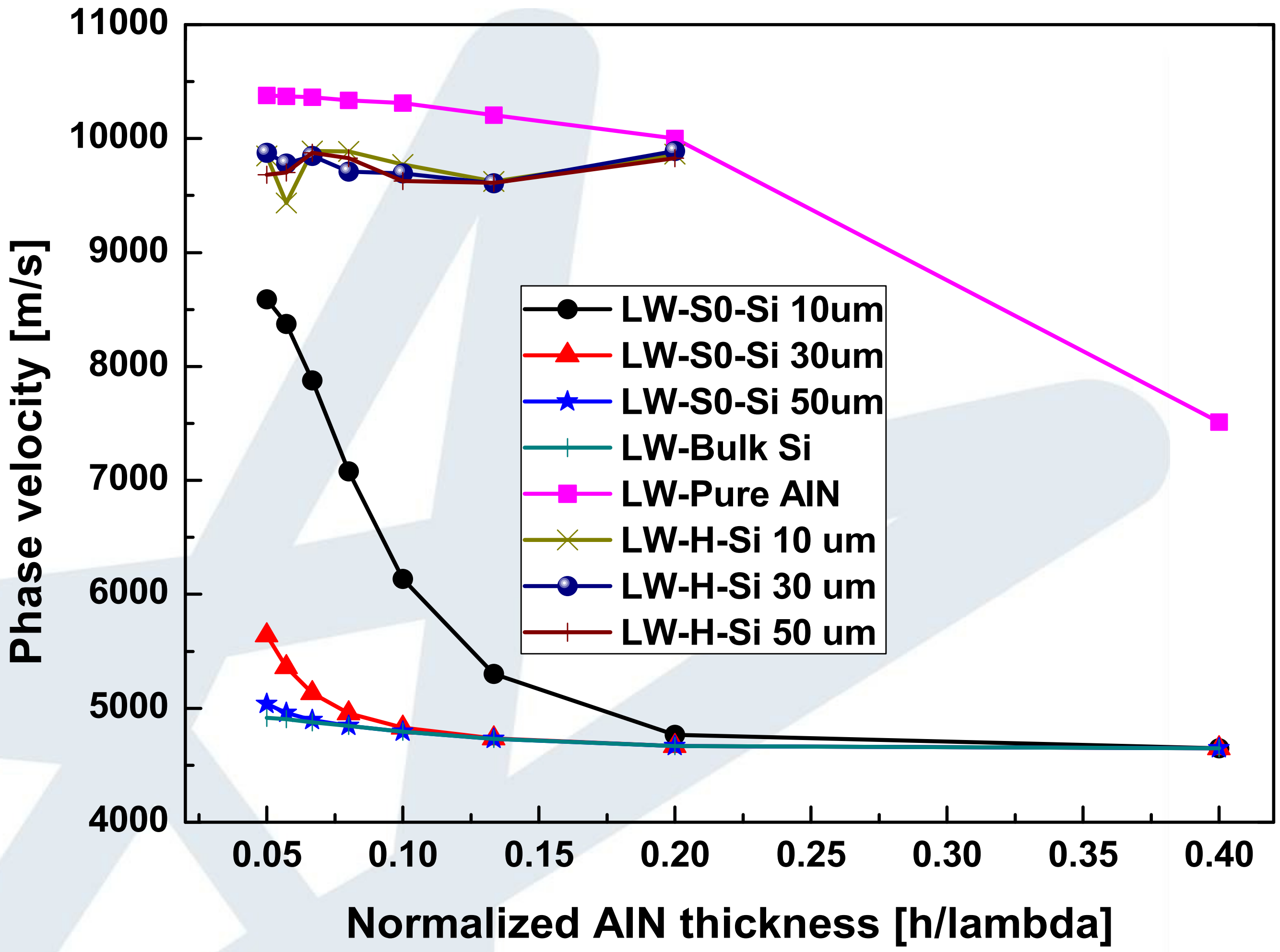
S_0 wave /SAW



511.078 MHz

Lamb wave

Simulation results



The simulated dispersion curves of LAMB waves

The phase velocity dispersive curve of the Lamb wave under different Si thickness (Bulk, 10 μm, 30 μm and 50 μm) are simulated. Compared with the phase velocity dispersion curves of Lamb wave in pure AlN/Al plate, higher order Lamb wave shows a non-dispersive behavior over a wide range.

Stress investigation of metal thin film microbolometer

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Metal (Pt, Au, Ag, Ni, …) and dielectric (SiO2, SiN, Al2O3, …) thin films are used extensively in microelectromechanical system (MEMS) devices as structural layer. Stress control of these films is of particular importance to guarantee integrity and reliability of the MEMS devices. Stress-free of film stacks is required to achieve membrane flatness, which is very critical in some MEMS devices, especially microbolometer to ensure optimum light exposure and absorption.

Stress is developed throughout the film deposition process due to lattice mismatch and thermal expansion coefficient difference between deposited film and material underneath. The film stress can be minimized by tuning the process parameters but it is a very time consuming and challenging task.

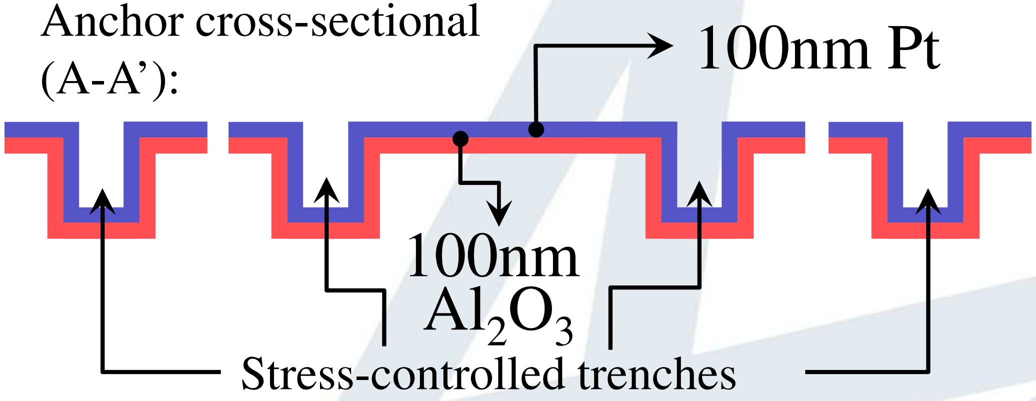
Simulations are thus employed to design the membrane structure that able to accommodate certain amount of film stress and still retain the membrane flatness. Stress-controlled trenches are added surrounding the free-standing membrane to improve the membrane flatness.

Simulation approach

Physics employed: Solid Mechanic (solid)

Materials

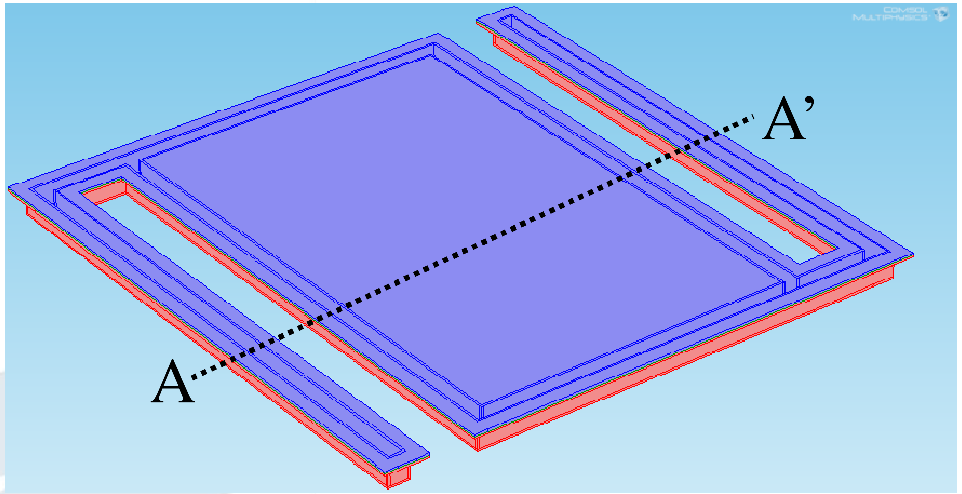
Anchor cross-sectional (A-A'):



100nm Pt

100nm Al_2O_3

Stress-controlled trenches

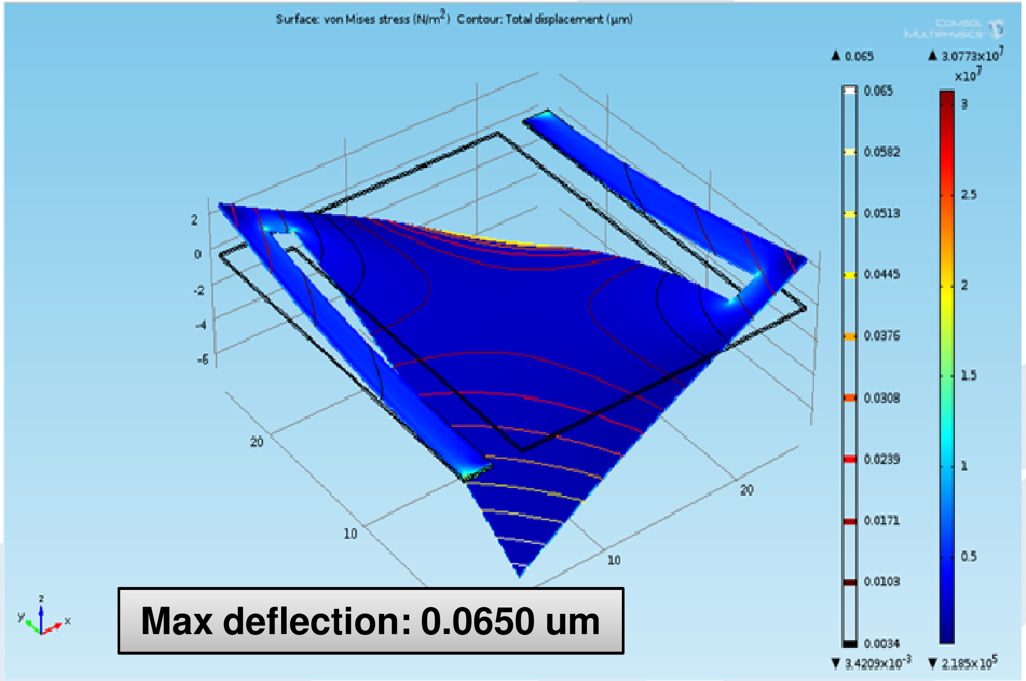


Conditions Setting

Domain	Linear Elastic Material	Initial Stress and Strain (Al2O3) Initial Stress and Strain (Pt)	S_o (N/m^2) $= \begin{matrix} 10e6 & 10e6 & 0 \\ 10e6 & 10e6 & 0 \\ 0 & 0 & 0 \end{matrix}$ (N/m^2) ε_o (1) = Default
Domain	Initial Values	Default	All domain
Boundary	Free	Default	All except "Fixed Constraint"
Boundary	Fixed Constraint		End of the two anchors

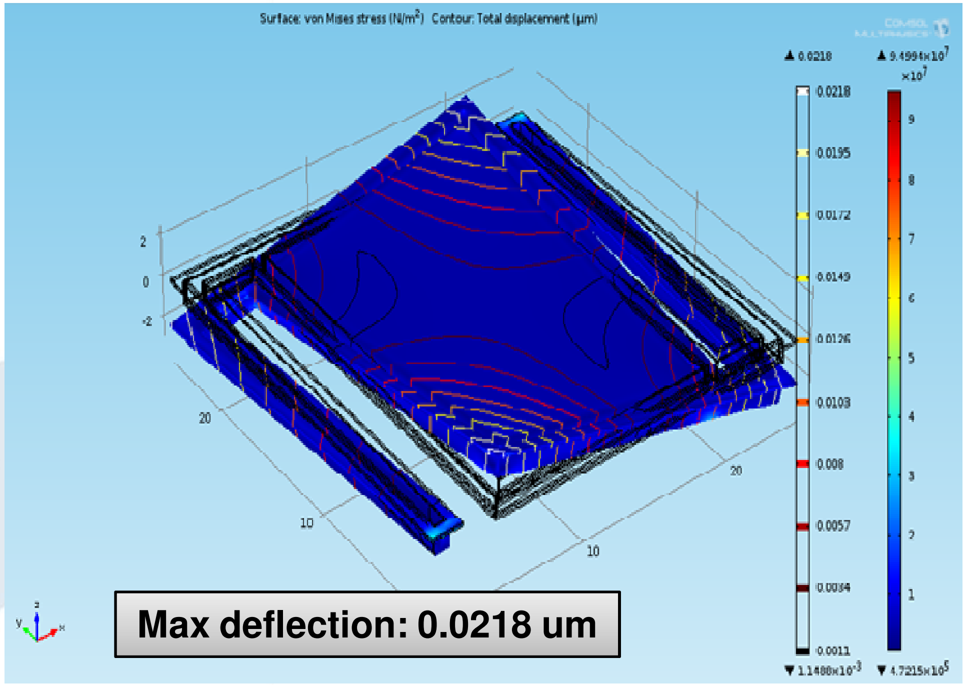
Simulation Results

Simulation without trenches



Max deflection: 0.0650 um

Simulation with trenches



Max deflection: 0.0218 um

By adding the stress-controlled trench at the periphery of the membrane, deflection reduced from 0.065µm to 0.0218µm.

Thermal behavior of acoustic wave microbolometer

Thermal behavior of acoustic wave microbolometer

Figure-of-merit (FOM) of a bolometer is determined by the device sensitivity and speed. Time dependent study of heat transfer physics in the simulation can be employed to obtain the thermal time constant (speed) and amount of temperature rise (sensitivity) of the bolometer.

The important parameters to describe a bolometer thermal behavior are heat capacity and thermal conductance. Since the dimension of all the materials used in the bolometer govern these two important parameters, device structure design is very critical.

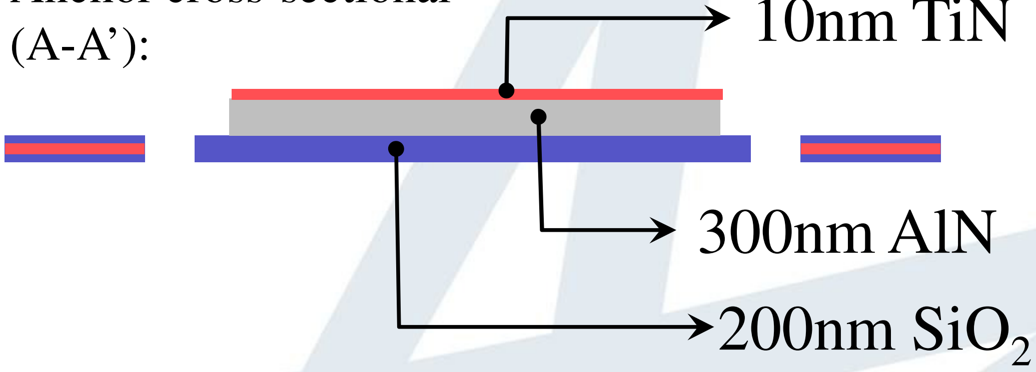
Depending on each particular application, bolometer can be designed with high speed or high resolution by optimizing the device structure design. However, trade-off is always needed between speed and resolution. Thus, the time dependent heat transfer is very useful to estimate the bolometer over performance.

Simulation approach

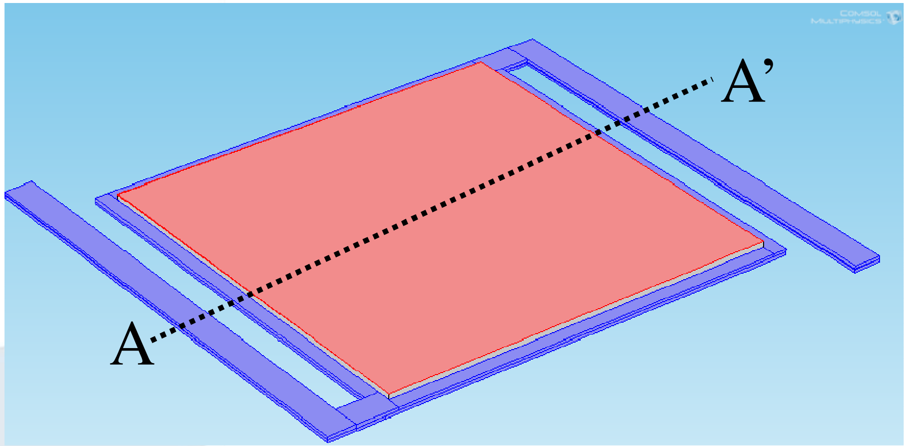
Physics employed: Heat Transfer (ht)

Materials

Anchor cross-sectional (A-A'):



3D model of AW Microbolometer

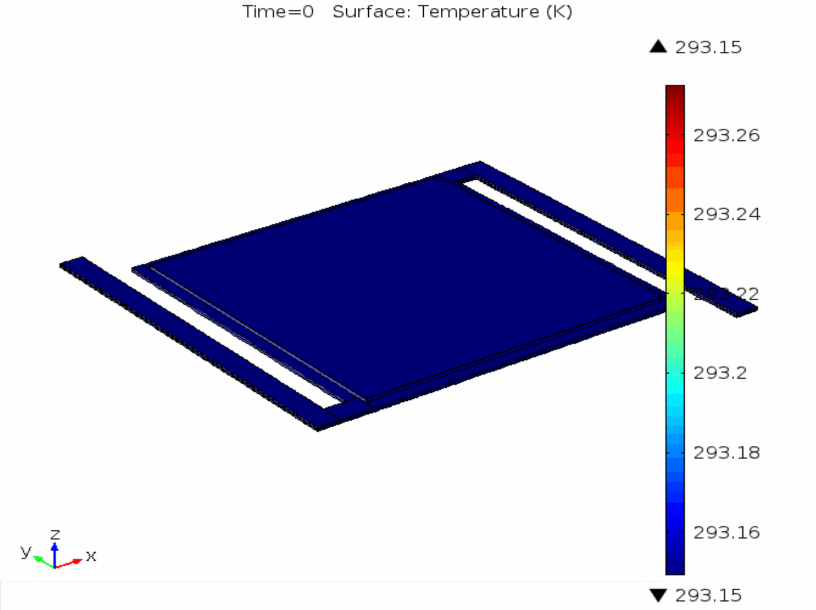


Conditions Setting

Domain	Heat Transfer in Solids	Default	All domain
Domain	Initial Values	Default	All domain
Boundary	Thermal Insulation	Default	All except "Temperature" and "Boundary Heat Source"
Boundary	Temperature	T = room temperature	End of the two anchors
Boundary	Boundary Heat Source	General source Q_b = 20*0.5*(sign(t)-sign(t-0.1)) W/m^2	Top surface of TiN on top of AlN

Simulation Results

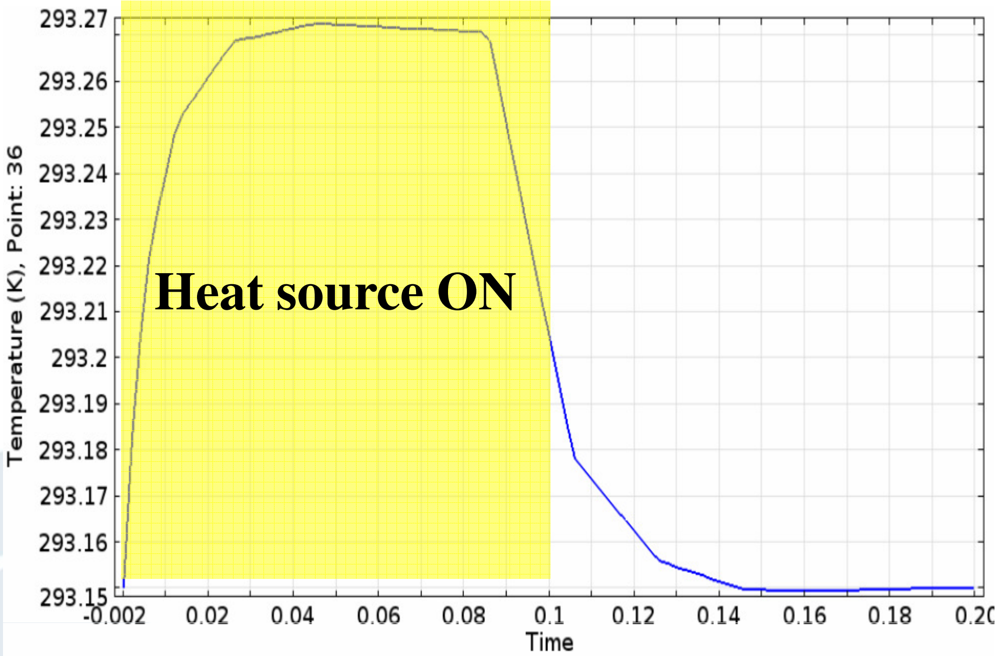
Thermal profile



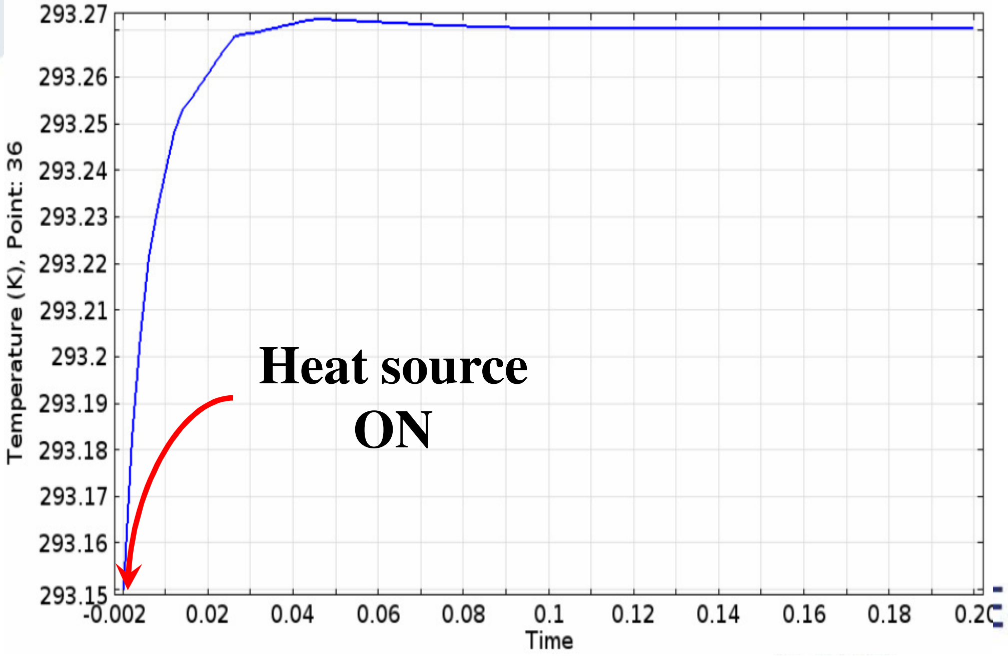
Temperature profile and the change of temperature with time.

The maximum temperature rise within the free-standing membrane was obtained directly from the simulation.

Thermal time constant can be extracted by fitting the curve below with exponential function.



Heat source ON



Heat source ON

Fluid-structure interaction (FSI) model for piezoelectric based energy harvest

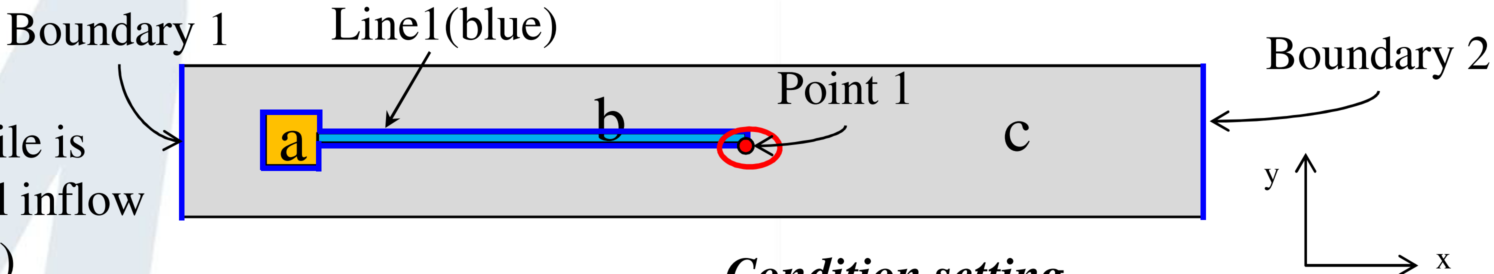
Fluid-structure interaction (FSI) model for piezoelectric based energy harvest

Plenty of energy can be taken from surrounding fluid sources. A classical flow pattern is the von Kármán vortex street that can form as fluid flows past an object. These vortices may induce vibrations in the object. This vortex shedding phenomenon is implemented by IME in the development of a MEMS micro-belt (AIN) based energy harvester.

Thus, have a good understanding on the fluid-structure interaction behavior is critical to guide the MEMS device design. In this simulation, we look into the fluid velocity, beam stress, force versus time and beam tip displacement in x and y directions.

Simulation approach

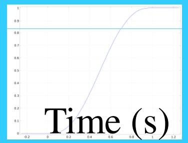
Physics employed: Fluid Flow>Fluid-Structure Interaction (fsi)



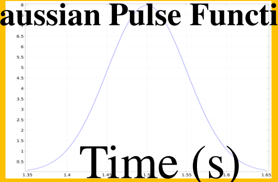
A parabolic velocity profile is prescribed at the left channel inflow

$$v^f(0, y) = 1.5\bar{U}\frac{y(H - y)}{(H/2)^2}$$

Definitions

Function (step 1)  Time (s)	Location: 0.5 Smoothing: size of transition zone (1)
Function (Gaussian Pulse 1)	Location: 1.5 (s) Standard deviation: 5e-2(s)
Integration	Line1(blue) All Boundary
Global Variable Probe	Lift: -intop1(fsi.T_ stressx) Drag: -intop1(fsi.T _stressy)

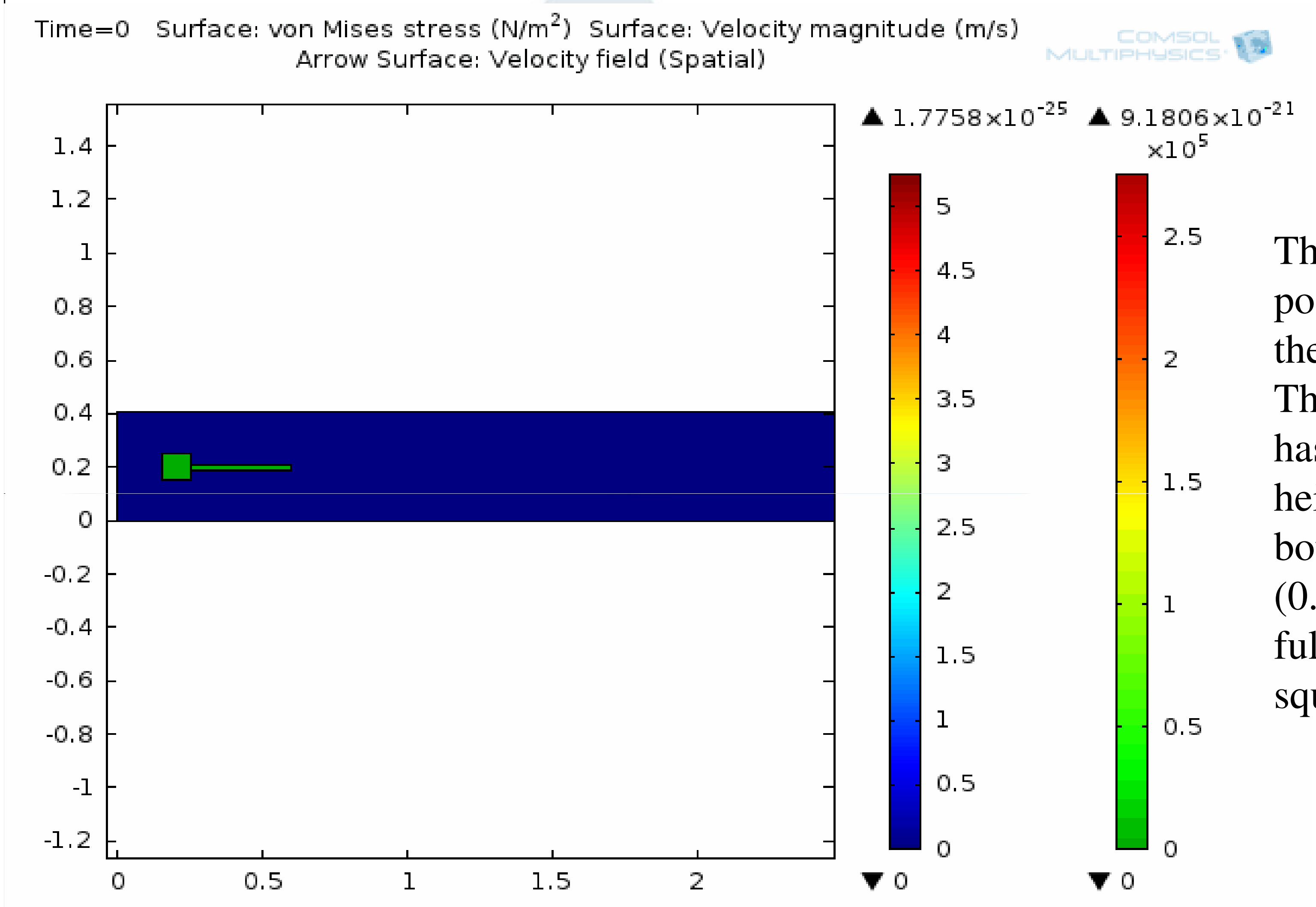
Condition setting

Fluid-Structure Interaction	Reference Point for Moment Computation>Discretization > Discretization of fluids choose **P2+P1** **P2: 2nd-order Lagrange elements model the velocity components** **P1: linear elements model the pressure**
Fixed Constraint 1	Block **a** fixed
Point Load 1	Force: **point 1** 0 x gp1(t) y ⟵ Gaussian Pulse Function  Time (s)
Inlet 1	Laminar Flow>Inlet select **Boundary1** *U*0: 1.5*2[m/s]*y*(0.41[m]-y)/(0.41[m]/2)^2*step1(t)
Outlet 1	Laminar Flow>Inlet select **Boundary2** *P*: 0

Mesh: Element size (Fine)

Studies: Time Dependent; Type 0 range (5, 5e-3, 6)

Simulation Results

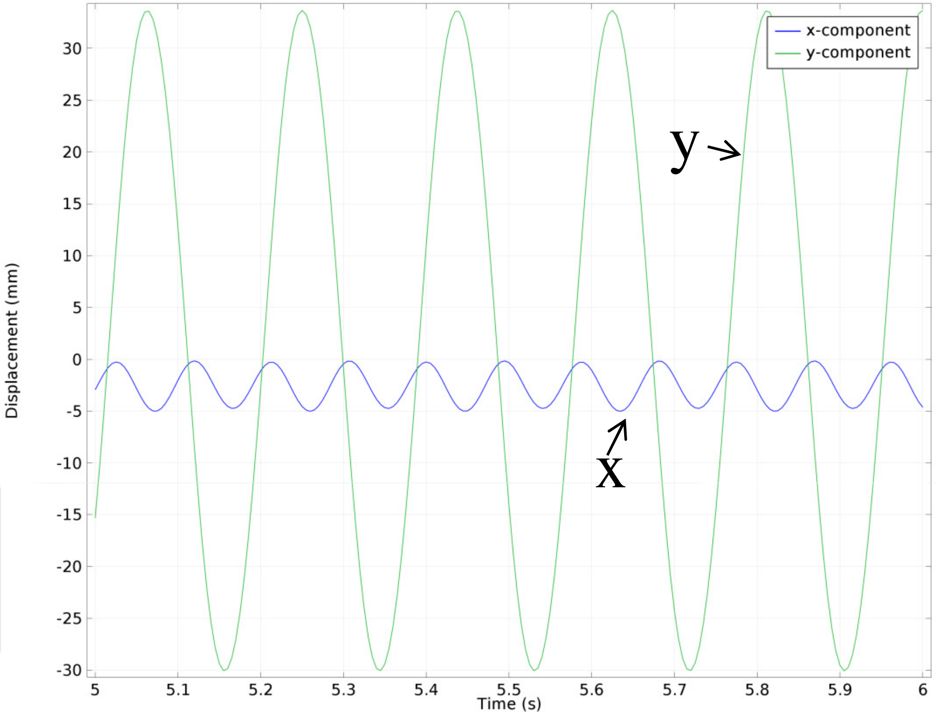


Channel length *L*: 2.5 m,
Channel height *H*: 0.41 m

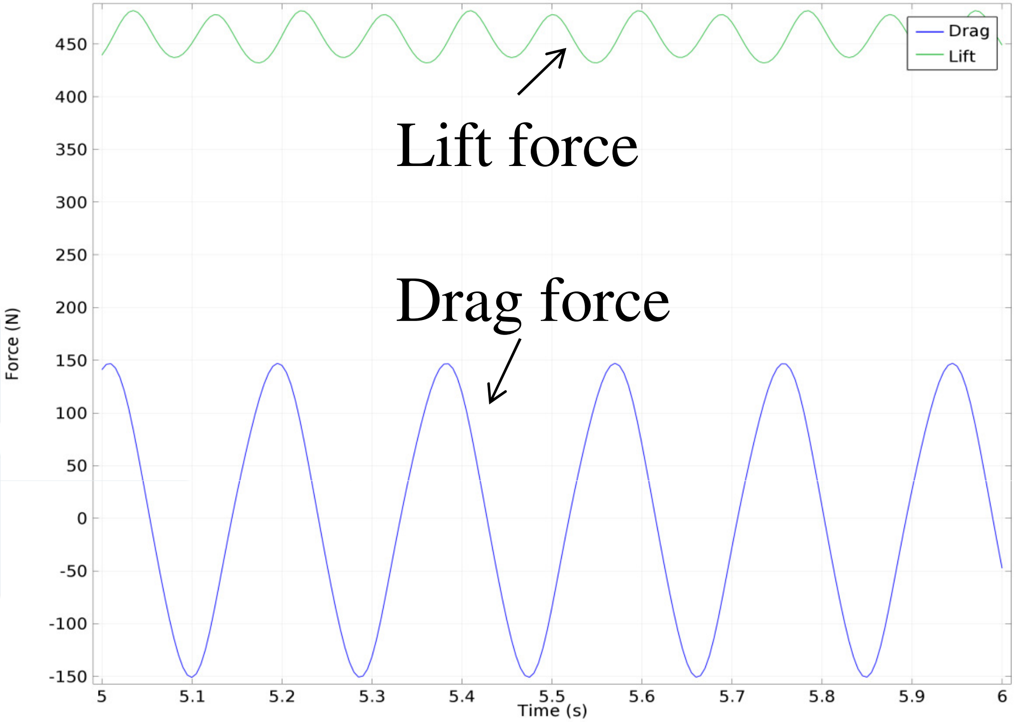
The bluff body square is positioned at *C*=(0.2, 0.2) and the side length is 0.1 m.
The elastic structure beam has length *l*=0.35 m and height *h*=0.02 m, the right bottom corner is positioned at (0.6, 0.19), and the left end is fully attached to the fixed square.

Simulation Results

Displacement of point 1



Lift and drag force of point 1



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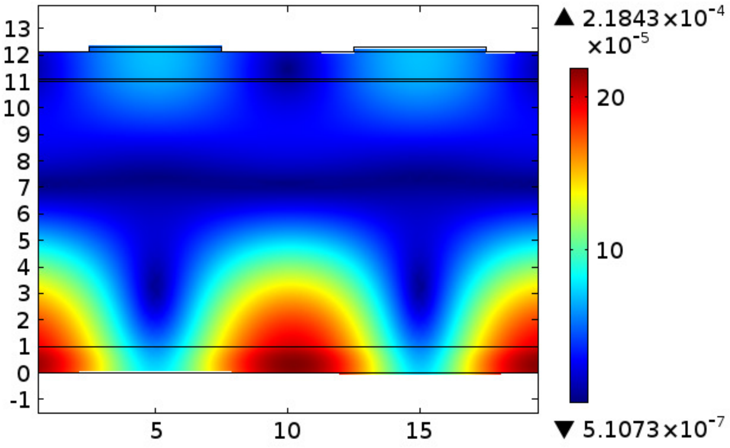
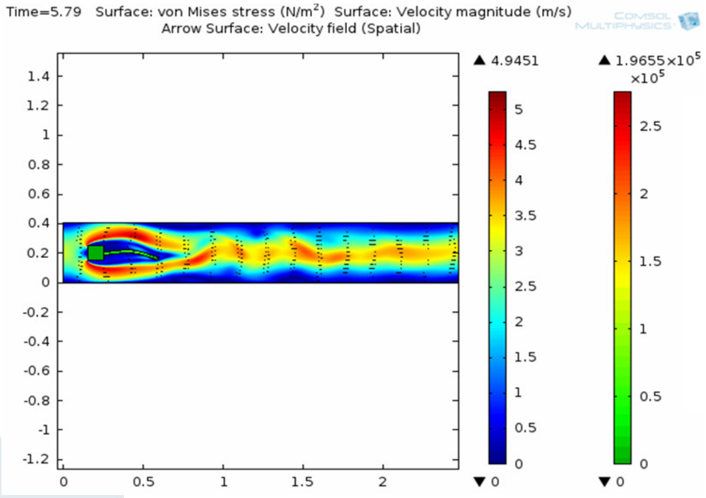
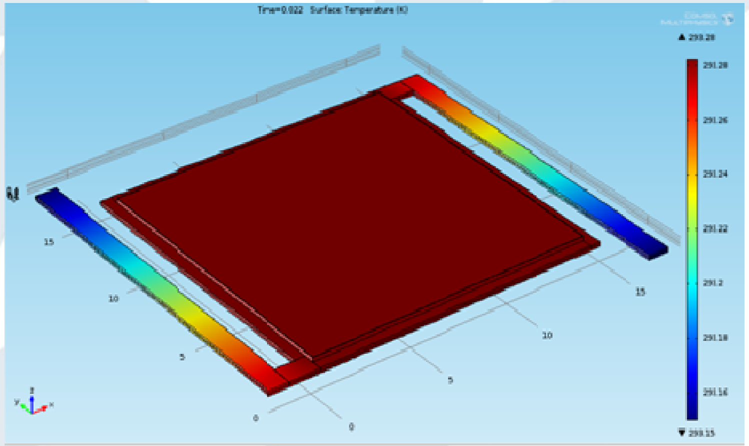
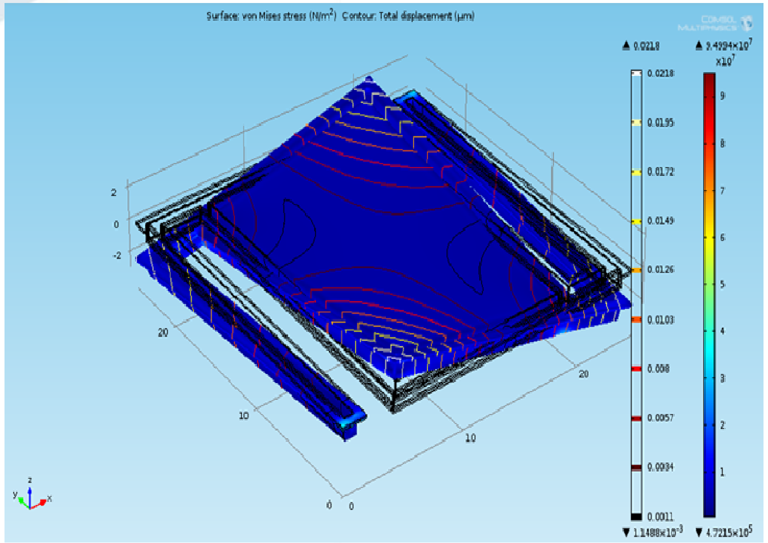




Thank you for your attention!
Questions?





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