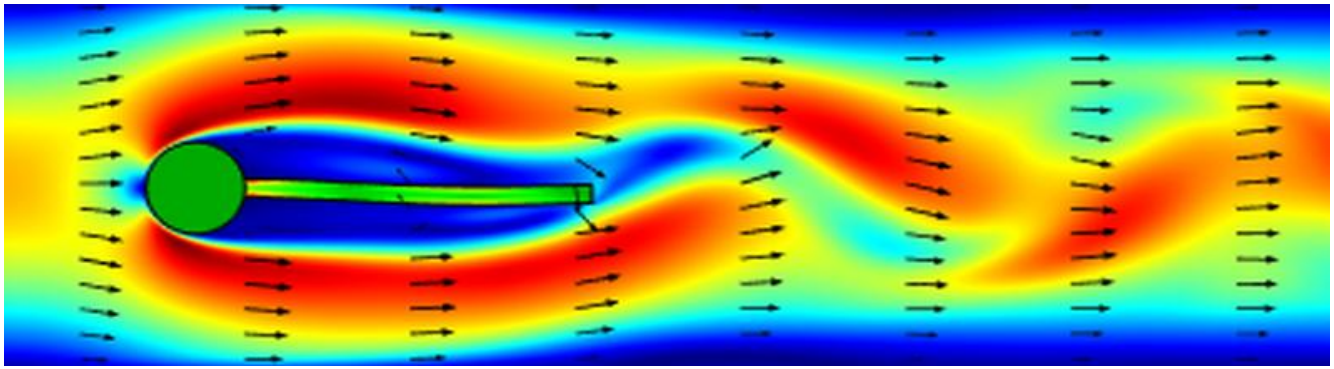
Fluid Coupling Effects of an Array of Oscillators



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Motivation for the project

- High speed non-contact AFM (atomic force microscopy/-e) is used to track the motion of live-cells
- Spatial resolution for AFM imaging of a whole mammalian cell is only about 50 nm.
- Why do we want to study coupling dynamics of AFM arrays in fluids ?

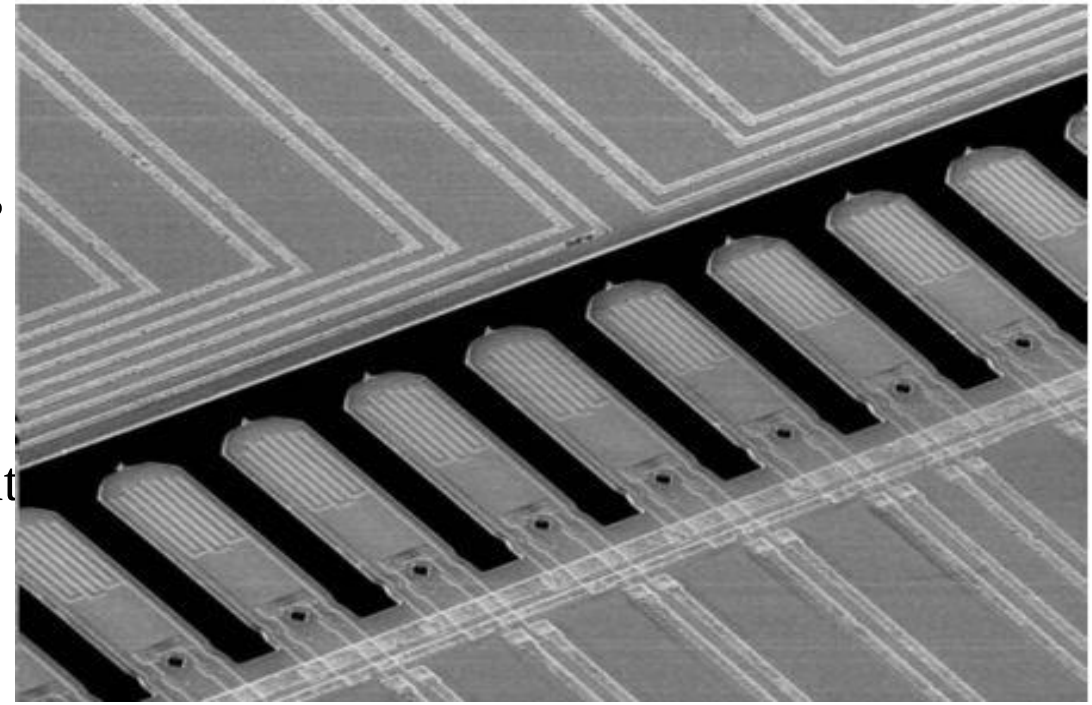

Figure 1: SEM image of PRONANO array

Model setup using COMSOL

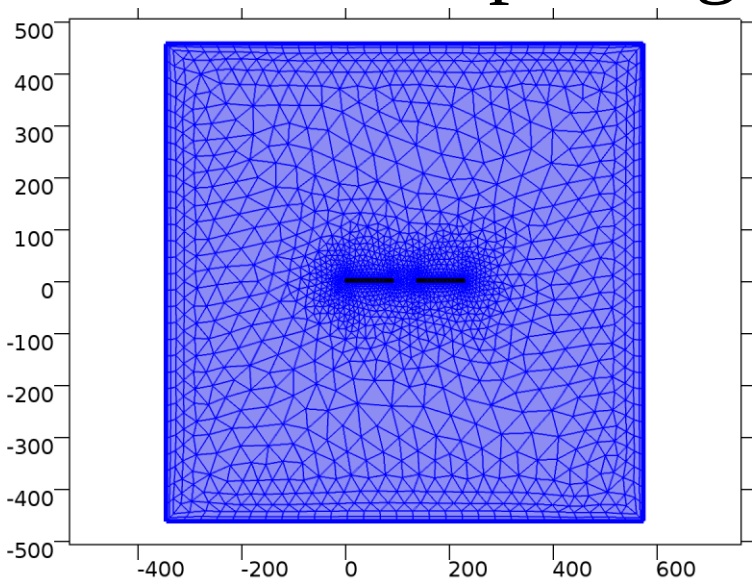

Figure 2: Meshed model of two cantilever cross-sections "far from the wall" in a fluid domain

Name	Expression	Value	Description
a	920[um]	9.2E−4 m	side length of fluid domain
z1	-460[um]	−4.6E−4 m	Height of the beam from surface
b	92[um]	9.2E−5 m	width of the beam
d	6[um]	6E−6 m	thickness of the beam
k	222.12[N/m]	222.12 N/m	equivalent spring stiffness
freq	63[kHz]	63000 Hz	drive frequency
F	1e-3[N]	0.001 N	force amplitude
g1	1/2*b	4.6E−5 m	gap width between beams

Table 1: Parameter list

Work flow

Two beam analysis, only one beam excited

- Varying gap widths g = b, 0.6b, 0.5b and 0.4b
- Both *" far from the wall"* and *"close to the wall"*

Two beam analysis, both beams excited

- Both beams excited in-phase for gap width g = 0.4b
- Both beams excited out-of-phase for gap width g = 0.4b
- Both *"close to a flat wall"* and *"close to a stepped/profiled wall"*

Three beam analysis, only one beam excited

- Only one beam excited at a time for gap width g = 0.4b
- *"close to a flat wall"*

Two beams: Only one beam excited, far from the wall study

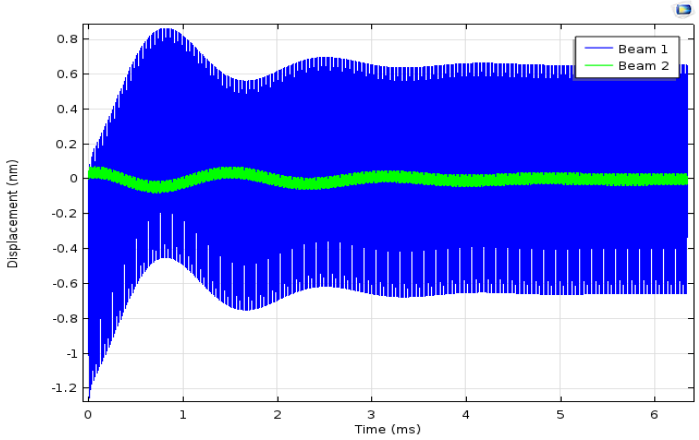

Figure 3: Displacement of two beams , gap width = b

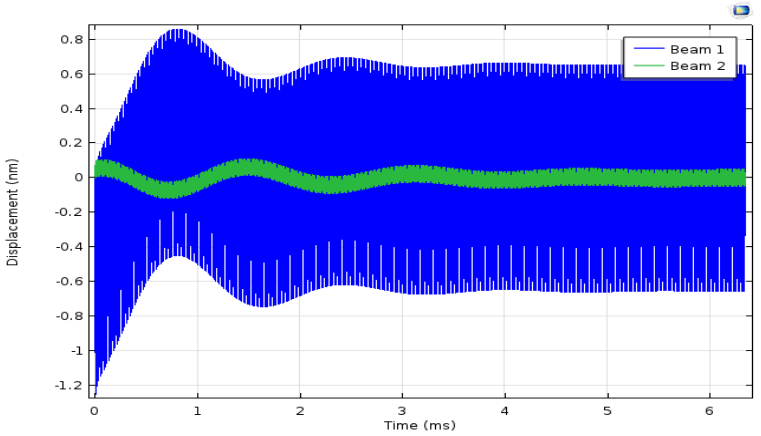

Figure 4: Displacement of two beams , gap width = 0.6b

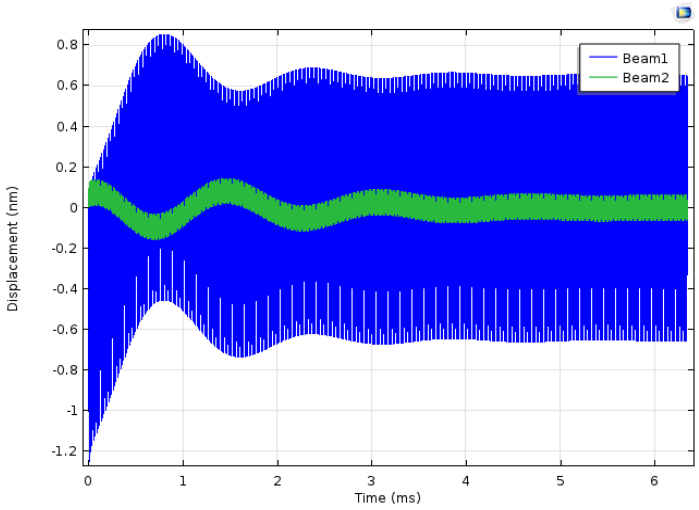

Figure 5: Displacement of two beams , gap width = 0.5b

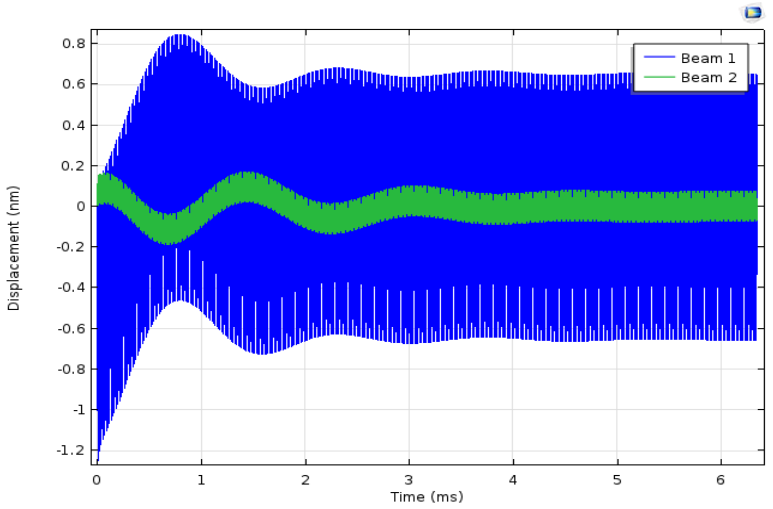

Figure 6: Displacement of two beams , gap width = 0.4b

Time history plots, gap width g = 0.4b

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Far from the wall

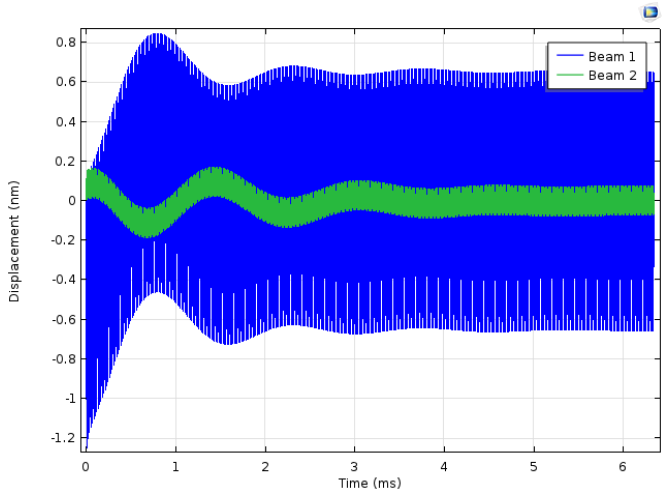

Figure 7: Displacement of two beams far from the wall, g =0.4b

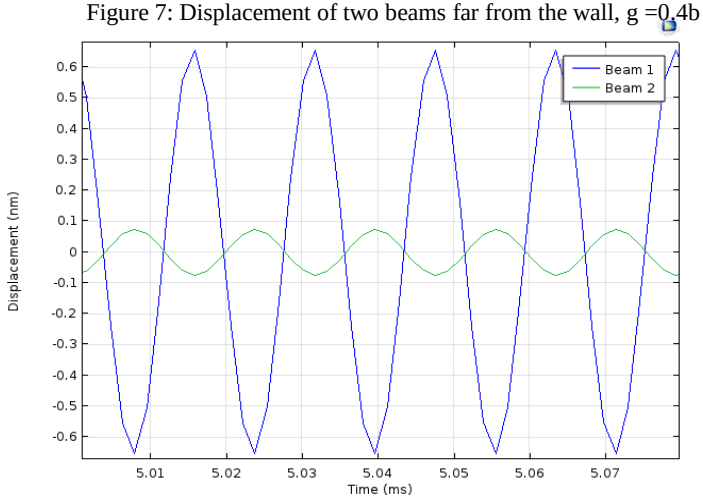

Figure 9: Steady-state plot far from the wall, g = 0.4b

Close to a flat wall

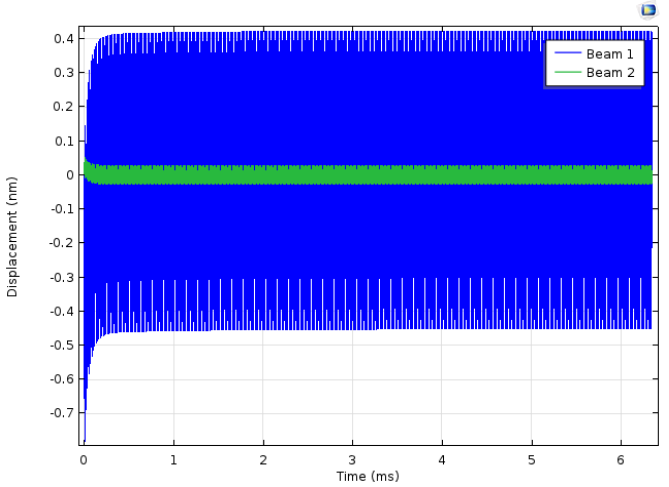

Figure 8: Displacement of two beams close to a flat wall, g = 0.4b

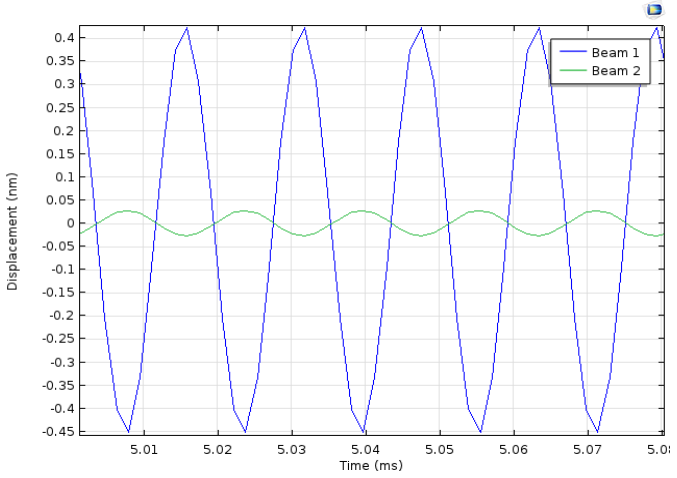

Figure 10: Steady-state plot close to a flat wall, g = 0.4b

Flow and pressure plots, g = 0.4b

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Far from the wall

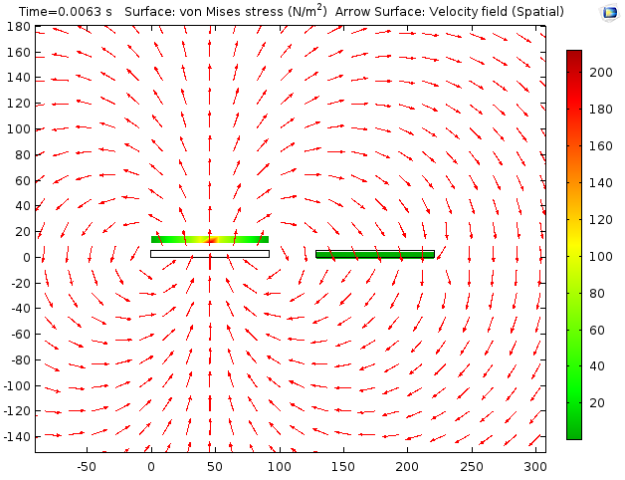

Figure 11: Flow and stress plot far from the wall

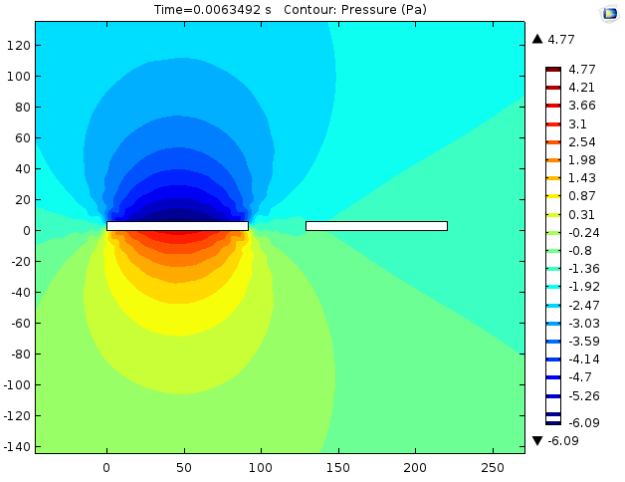

Figure 13: Pressure contour far from the wall

Close to the wall

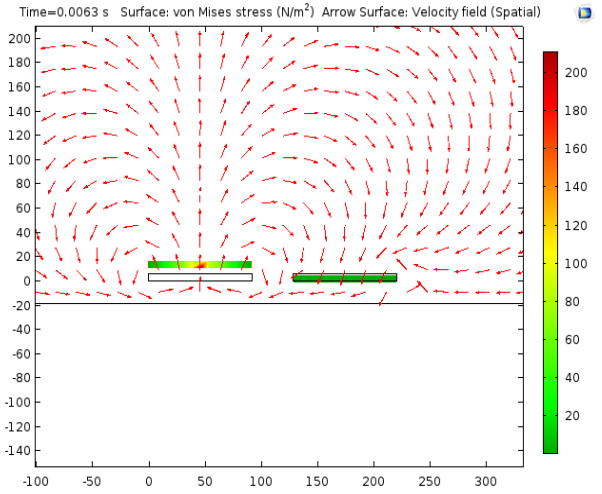

Figure 12: Flow and stress plot close to the wall

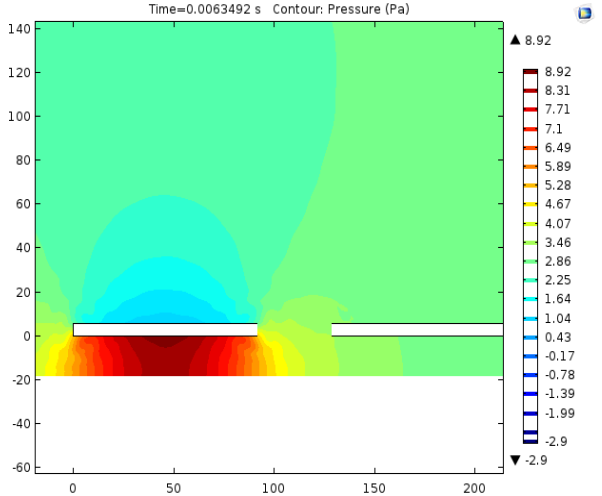

Figure 14: Pressure contour close to the wall

Two beams excited close to the wall

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In-phase excitation

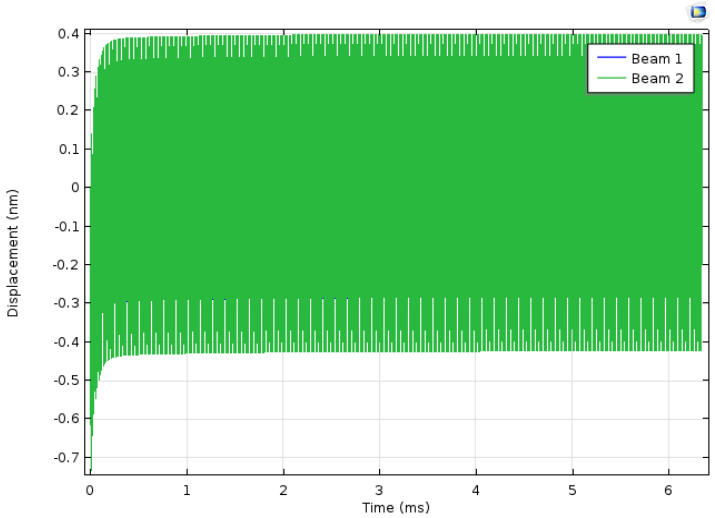

Figure 15: Displacement of two beams excited in-phase, g =0.4b

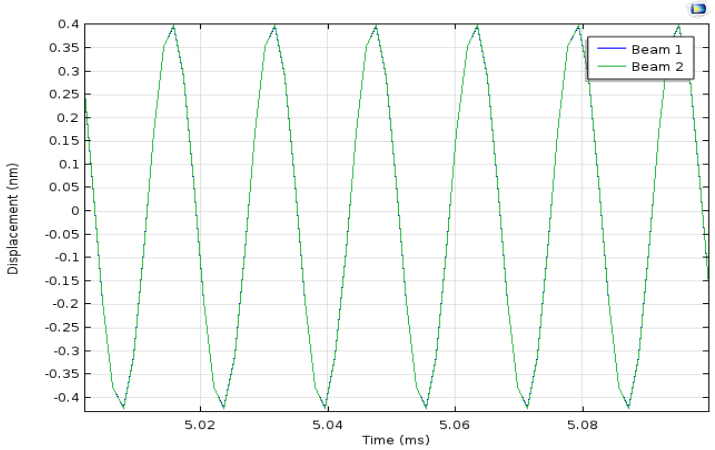

Figure 17: Steady-state plot of two beams excited in-phase, g =0.4b

Out-of-phase excitation

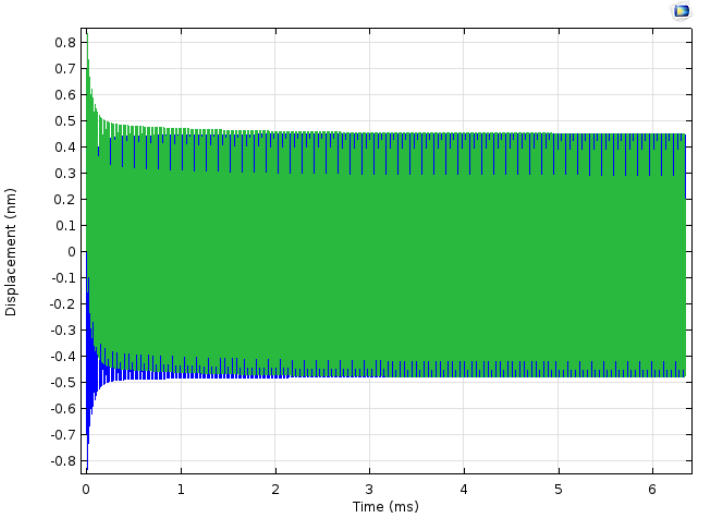

Figure 16: Displacement of two beams excited out-of-phase, g =0.4b

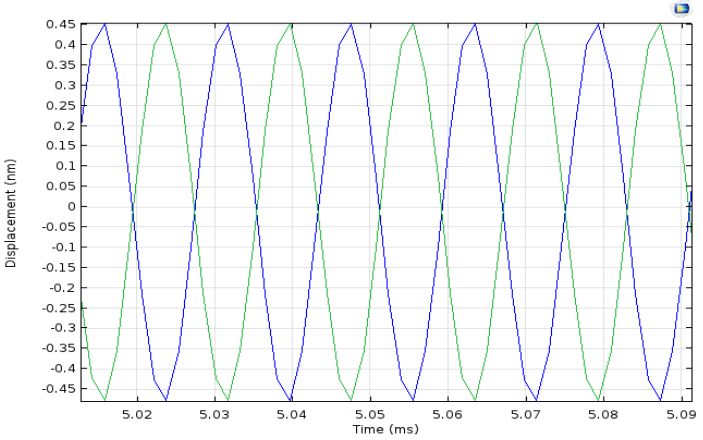

Figure 18: Steady-state plot of two beams excited out-of-phase, g =0.4b

Flow and stress plots, g = 0.4b

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In-phase excitation

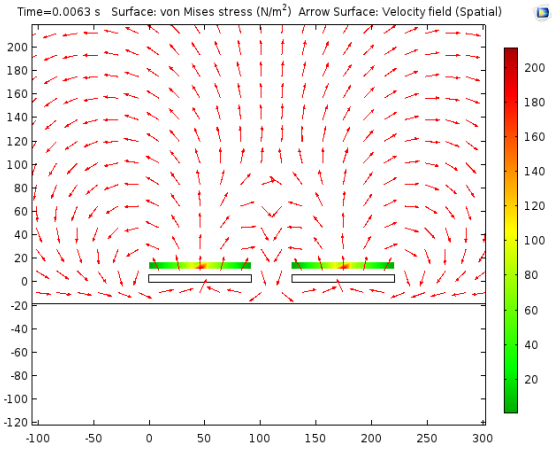

Figure 19: Flow and stress plot of beams excited in-phase, g =0.4b

Out-of-phase excitation

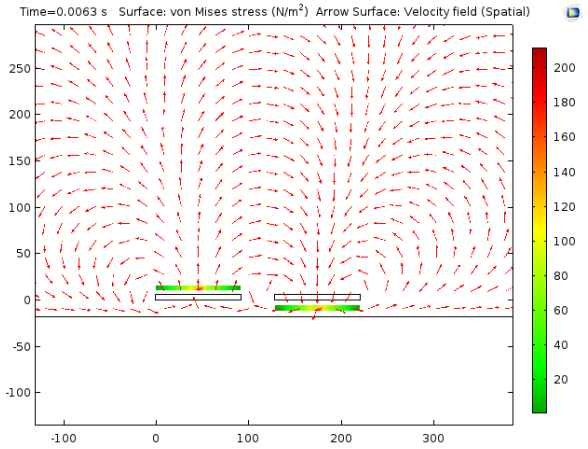

Figure 20: Flow and stress plot of beams excited out-of-phase, g =0.4b

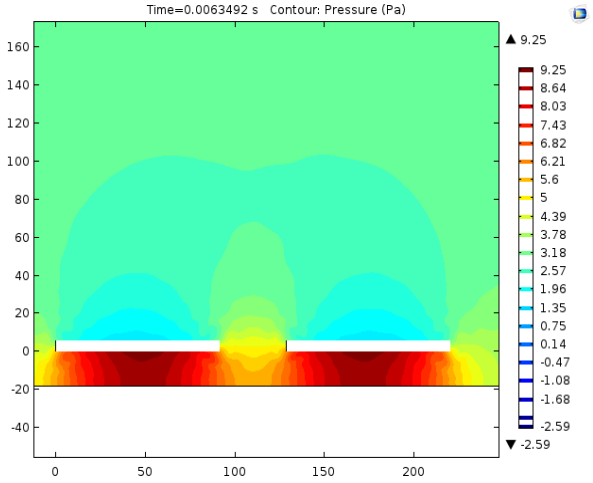

Figure 21: Pressure contour of beams excited in-phase, g =0.4b

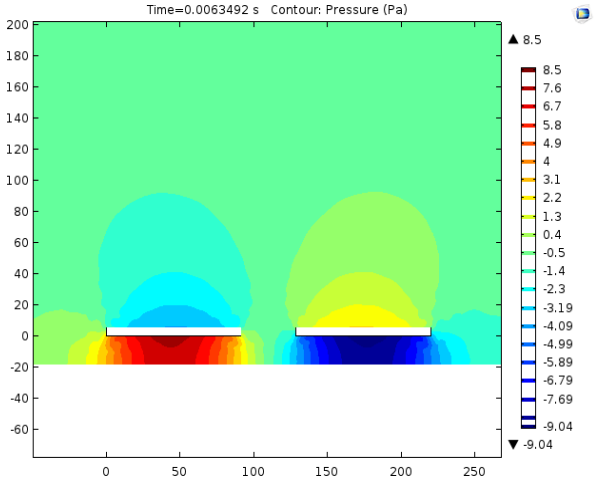

Figure 22: Pressure contour of beams excited out-of-phase, g =0.4b

Three beams: Effect of neighbouring beams

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Beam 1 excited

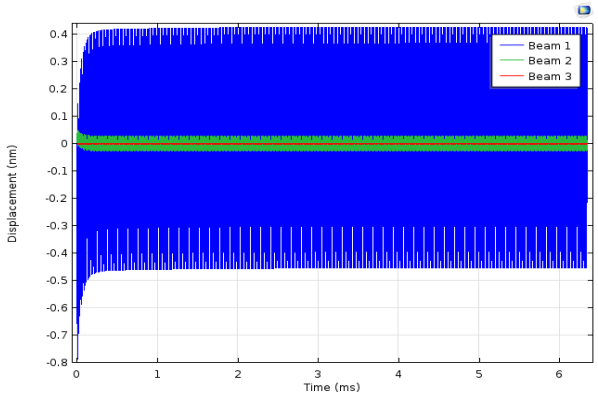

Figure 23: Displacement of three beams , g =0.4b

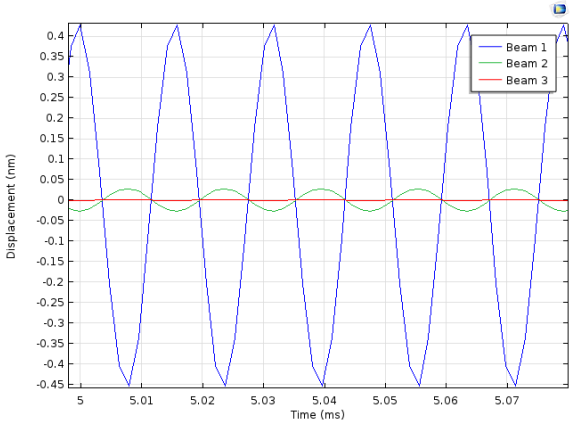

Figure 25: Steady-state plot of three beams , g = 0.4b

Beam 2 excited

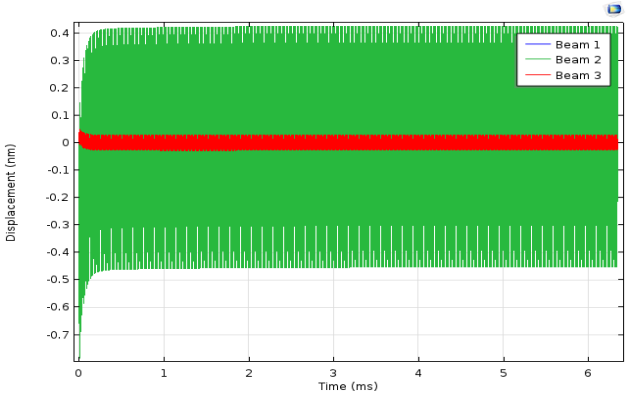

Figure 24: Displacement of three beams , g =0.4b

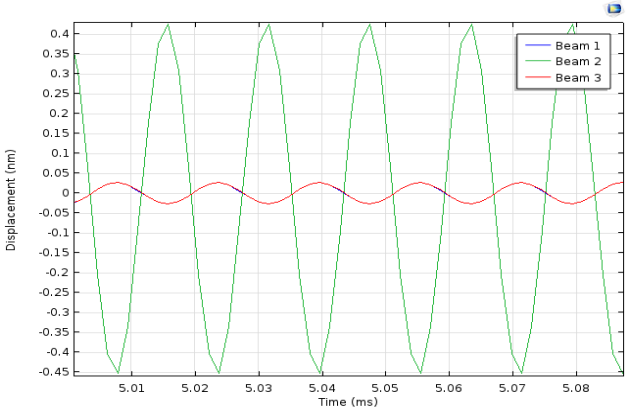

Figure 26: Steady-state plot of three beams, g = 0.4b

Three beams: Flow and pressure plots, g = 0.4b

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Beam 1 excited

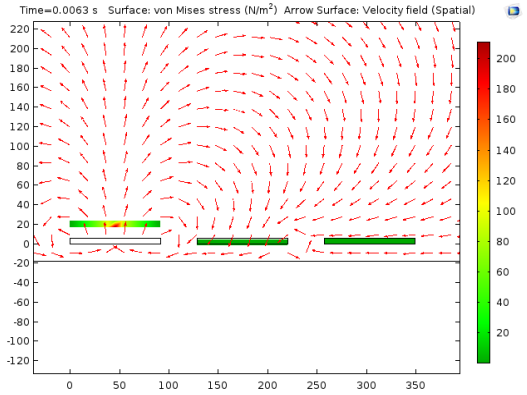

Figure 27: Flow and stress plot of three beams, g = 0.4b

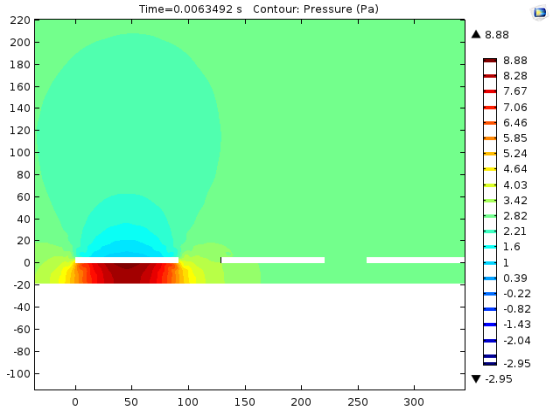

Figure 29: Pressure contour of three beams, g = 0.4b

Beam 2 excited

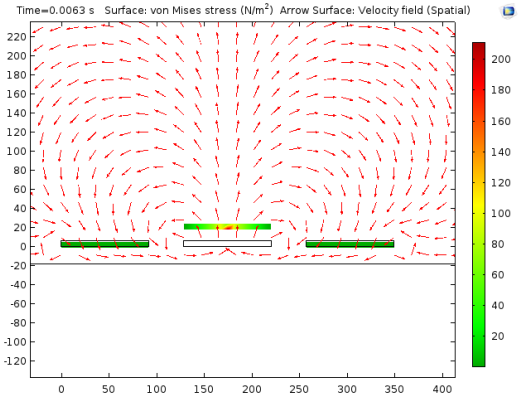

Figure 28: Flow and stress plot of three beams, g = 0.4b

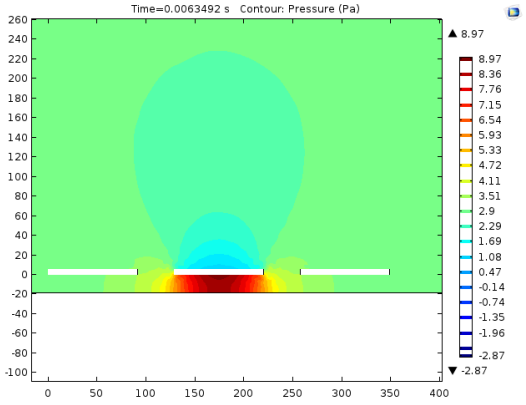

Figure 30: Pressure contour of three beams, g = 0.4b

Two beams:Both beams excited in unison

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Flat wall

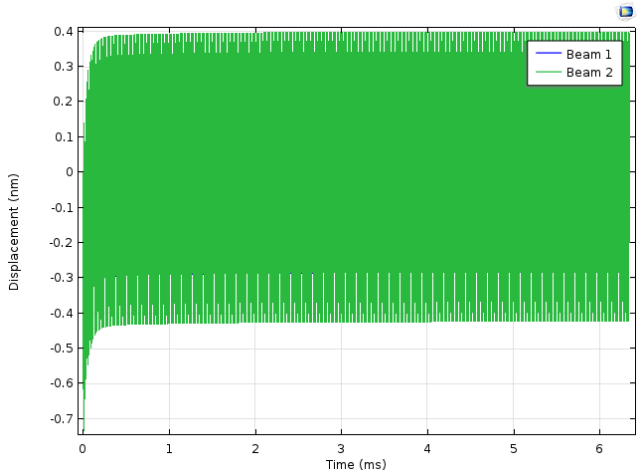

Figure 31: Displacement of two beams , g =0.4b

Stepped wall

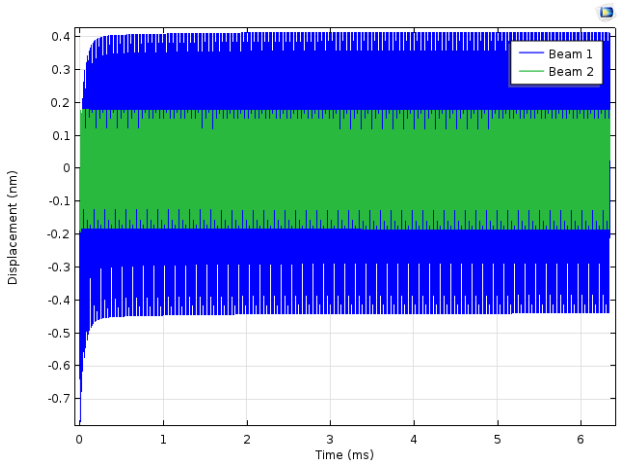

Figure 32: Displacement of two beams , g =0.4b

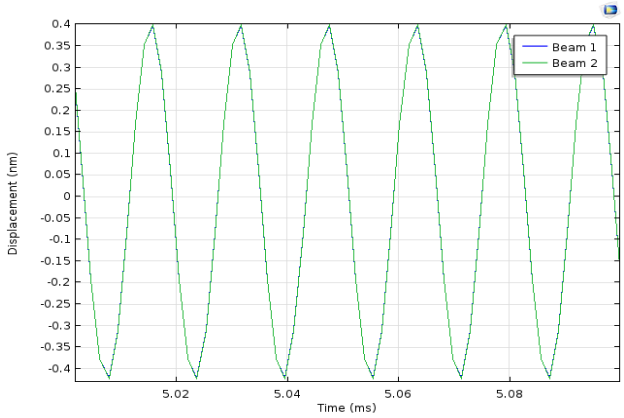

Figure 33: Steady-state plot of two beams , g =0.4b

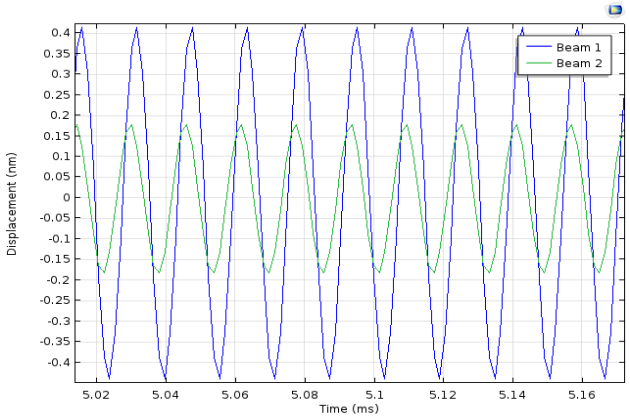

Figure 34: Steady-state plot of two beams , g =0.4b

Two beams: flow and pressure plots

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Flat wall

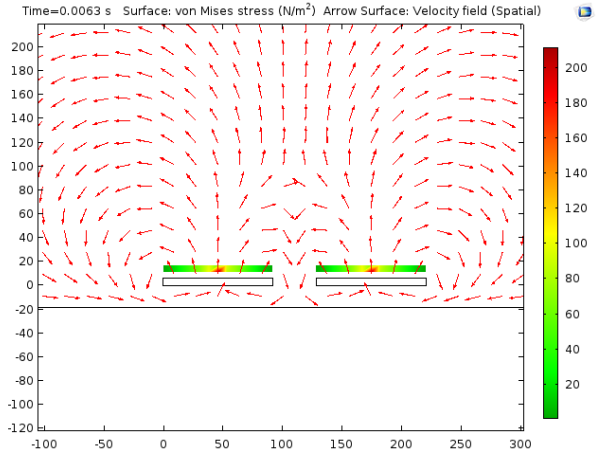

Figure 35: Flow and stress plot of two beams, g = 0.4b

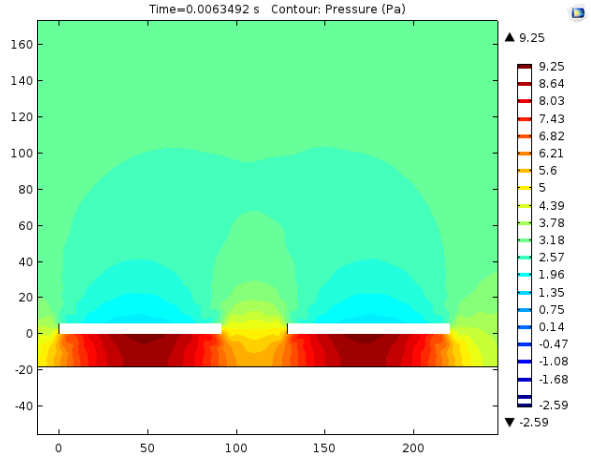

Figure 37: Flow and stress plot of two beams, g = 0.4b

Stepped wall

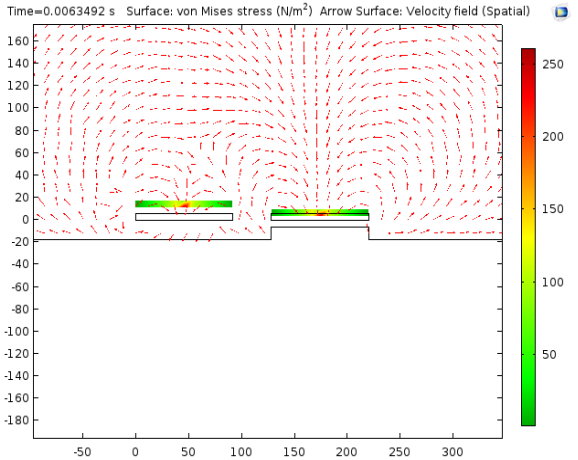

Figure 36: Flow and stress plot of two beams, g = 0.4b

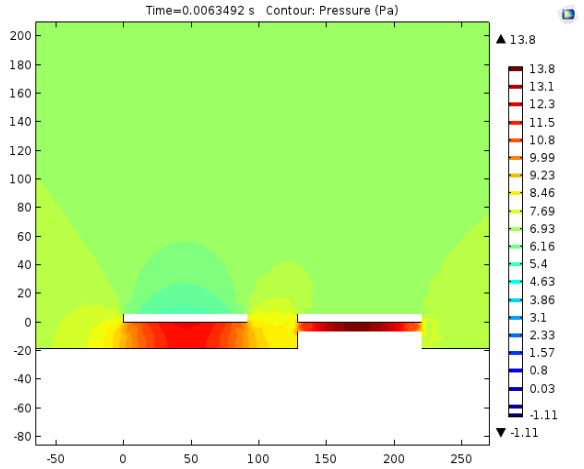

Figure 38: Flow and stress plot of two beams, g = 0.4b

Summary

- **Varying gap width study:** Strong coupling occurs as the gap width decrease between the beams.

- **Varying height study:** Reduced amplitude of the beam compared to the "far away from the wall" case

- **Varying excitation conditions:**

  Only one beam excited: beams vibrate in a out-of-phase fashion

  Both beams excited: results in a higher amplitude when excited out-of-phase.

- **Effect of non-neighbouring beams:** hardly have any influence on the dynamics of the system when coupled only via fluid

- **Varying wall configurations:** results in a phase shift when excited in close proximity to a stepped wall whereas beams vibrate completely in-phase when vibrating close to a flat wall.