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Design of a MEMS Capacitive Comb-drive Accelerometer

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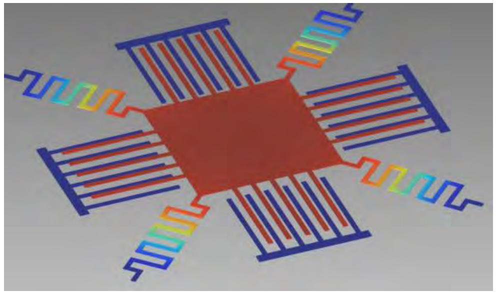
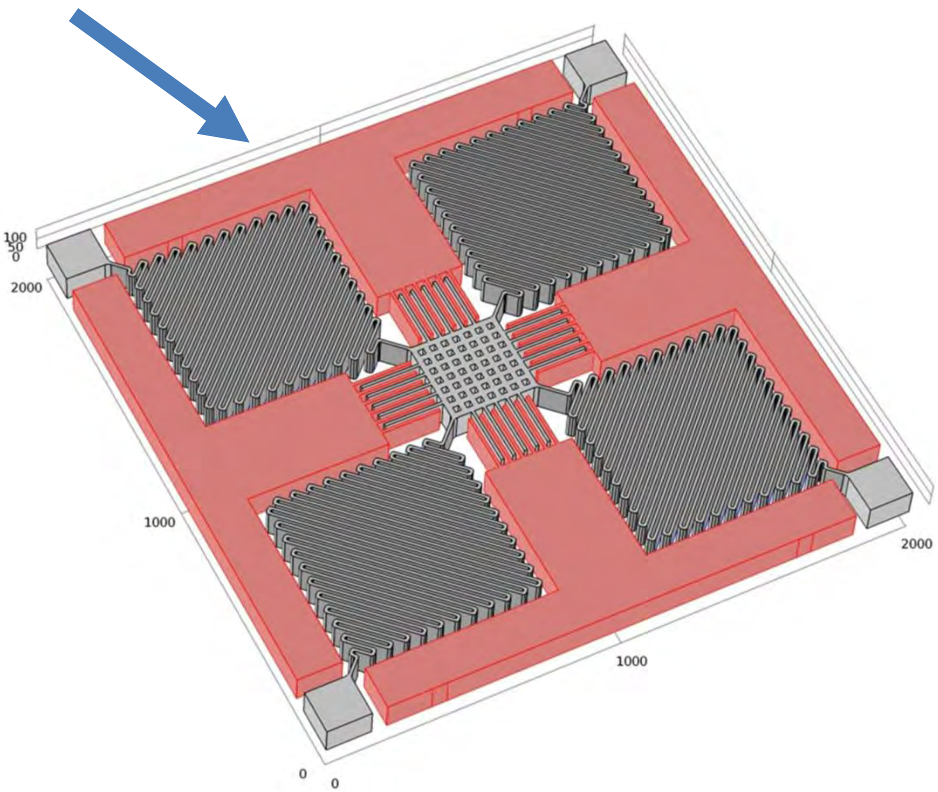
Introduction

- Micro-scale accelerometers
  - automotive safety,
  - navigation,
  - audio-video,
  - health monitoring.
- MEMS accelerometers
  - excellent sensitivity
  - wide dynamic range
  - low cost and mass produced.
- COMSOL Multiphysics to study the working principal and dynamic performances

Accelerometer Design





- The proof-mass: Etch-released holes to compensate for squeezed air film damping

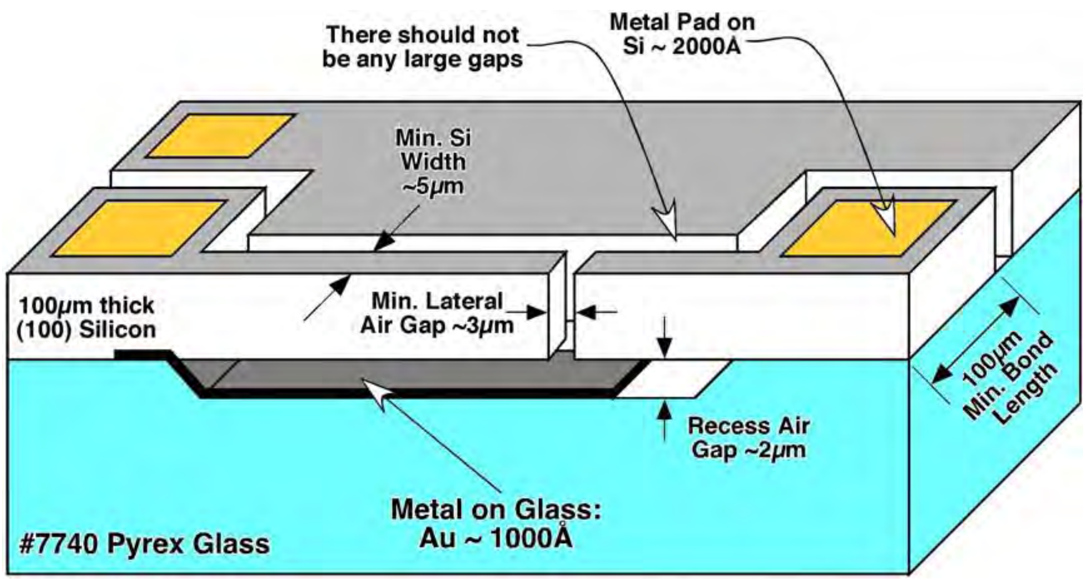
  COMSOL Multiphysics was used to model for this gas-effect and the Reynolds equations were modified within the software to expand its capabilities.

  The accelerometer geometry designed in AutoCad and imported into COMSOL for structural and modal analysis.

  Limited to 5g (health monitoring)

Microfabrication

- Silicon-on-Glass (SOG) process developed by University of Michigan, Lurie Nanofabrication Facility (LNF)
  - Si: Thickness: 100µm, (100) orientation, Doping: Boron, Resistivity: 0.005 Ωcm
  - Metal on top of silicon for electrical connection
  - Metal under the silicon layer for actuation
  - Recess air gap of about 3µm

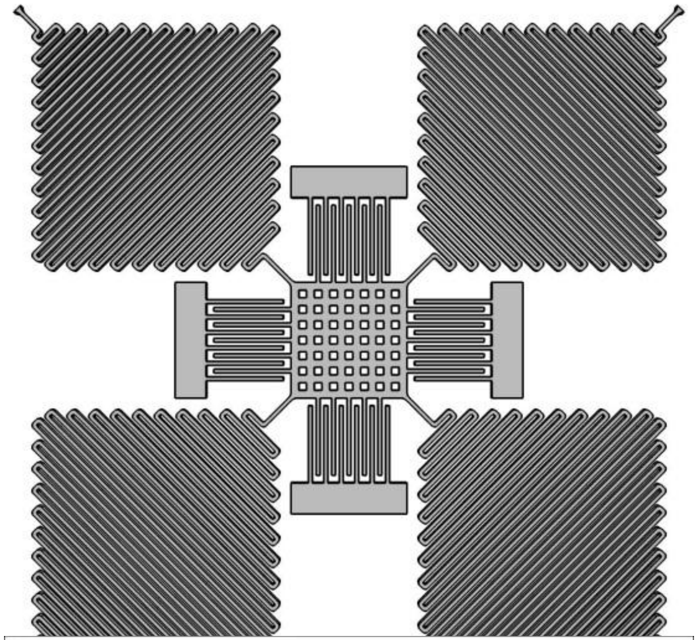


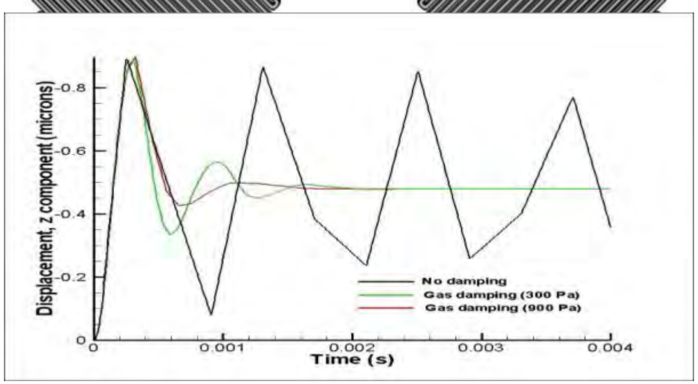
Parameters

Parameter	Value	Unit
Area of Accelerometer	2000×2000	μm^2
Area of proof-mass	395×395	μm^2
Thickness of proof-mass	100	μm
Young modules of silicon	1.67×10^{11}	N/m^2
Poisson ratio of the silicon	0.3	
Density of Silicon	2300	Kg/m^3
Relative permittivity of silicon	11.9	
Viscosity of air at 25º	1.1839×10^{-5}	Pa.s
Mean free path of air at 25º	6.78×10^{-8}	m
Relative permittivity of air	1	

- The external acceleration: body force.
- The total simulation time : 4 ms with 0.01 ms steps.
- 5g threshold acceleration in direction x (in-plane) and direction z (out-of-plane) in all simulations.
- A 3D tetrahedral element, 10 node, size-varying mesh was used in all simulations.

Dynamics

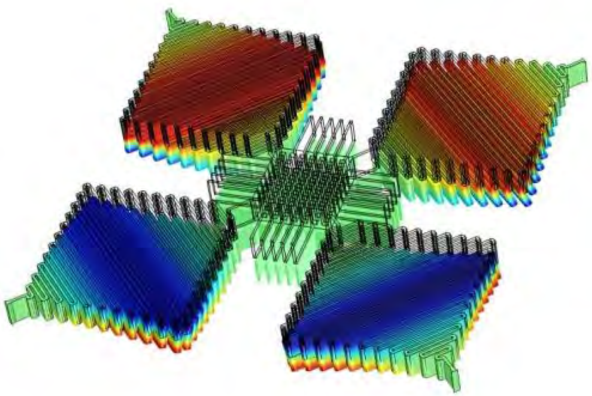




- Simplified geometry: only the moving parts
  - silicon proof-mass
  - four serpentine springs fixed at their ends.

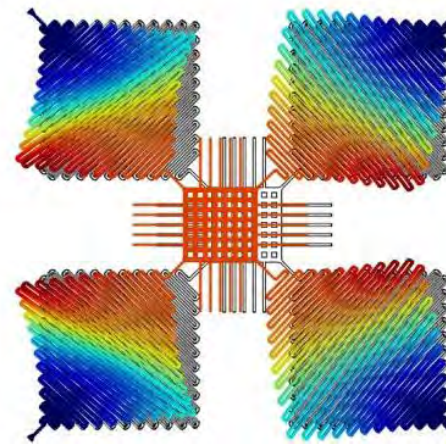
- The z displacement of the proof-mass center under
  - 0 Pa
  - 300 Pa
  - 900 Pa

Dynamics (ctd.)

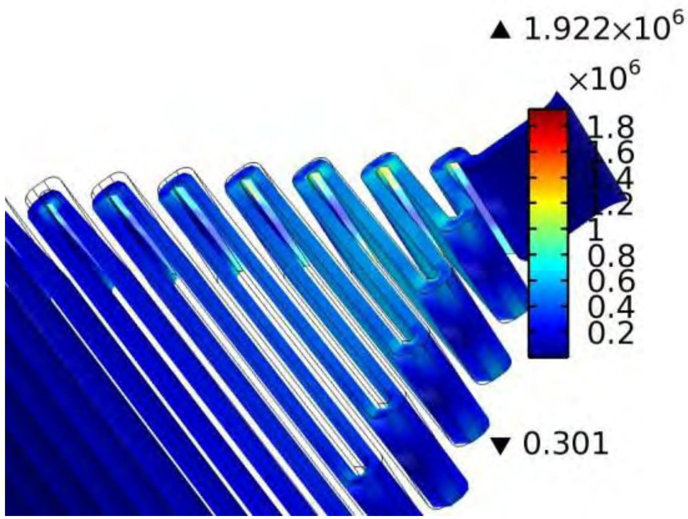


0.25 ms, 0.9 μm in z-

maximum displacement in the z-, and x- directions



0.5 ms, 1.4 μm in x-

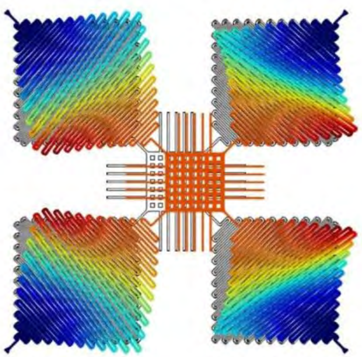


the contour of von-mises stress at the curved sections of the serpentine spring

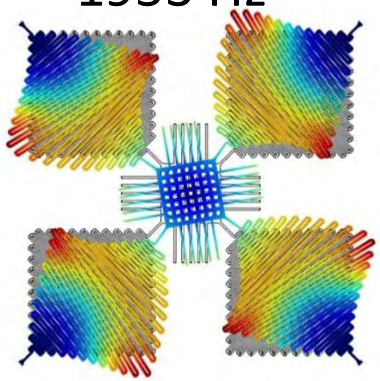
Max stress < 2 MPa

Modal Analysis

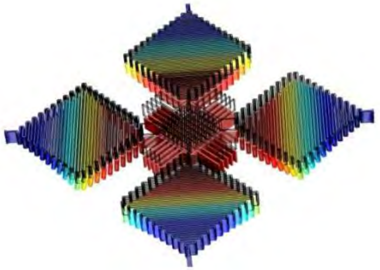
1280 Hz



1953 Hz



1838 Hz



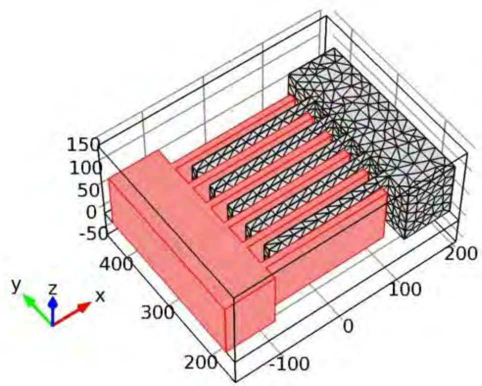
Order	Resonant frequency (Hz)	Mode shapes
1&2	1280	Vibrating by x or y axis (In-plane mode)
3	1838	Vibrating in z axis (out-of-plane mode)
4	1953	Vibrating along z axis (rotational mode)
5	39105	Vibrating along y or x axis (rotational mode)

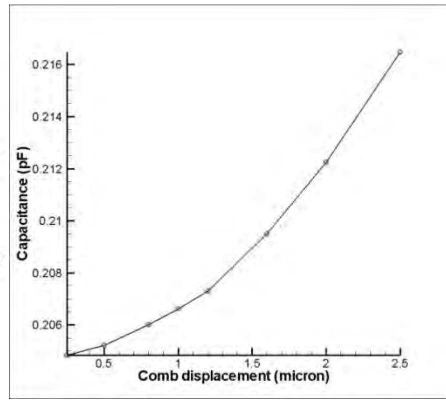
Trade-off

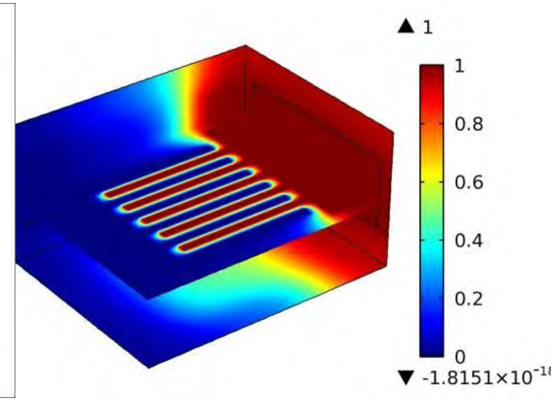
Lower spring stiffness:

- More deflection
- Lower resonance frequency

Electrostatic Analysis







- Capacitance change due to the Deflection of the proof-mass
- Interdigitated capacitors between the moving fingers attached to the proof mass and the fixed fingers attached to the frame.
- The differential capacitance and hence the circuit output voltage is proportional to the difference between gaps in the right and left side of each finger, as shown in the figure below.

Fabrication is in progress…

- Proposed design was simulated and optimized.
- We acknowledge the National Nanotechnology Infrastructure Network Computation project, NNIN/C, at Michigan for computational resources.