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Use of COMSOL Multiphysics for automated electrostatic MEMS sensor design

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Outline

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 - ⊙ Design goal
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 - ⊙ Process flow
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- Geometry check
- **Natural frequency computation***
- **Static deflection computation***
- Static pull-down check
- **Frequency response computation***
- Fitness computation

**indicates use of COMSOL Multiphysics*

Introduction

Application

An electrostatically actuated MEMS resonant mass sensor composed of a fixed-free, poly-silicon microbeam capable of capacitive sensing.

The design tool is a genetic algorithm based optimization process in which device configurations are defined by a *discrete* string of bits.

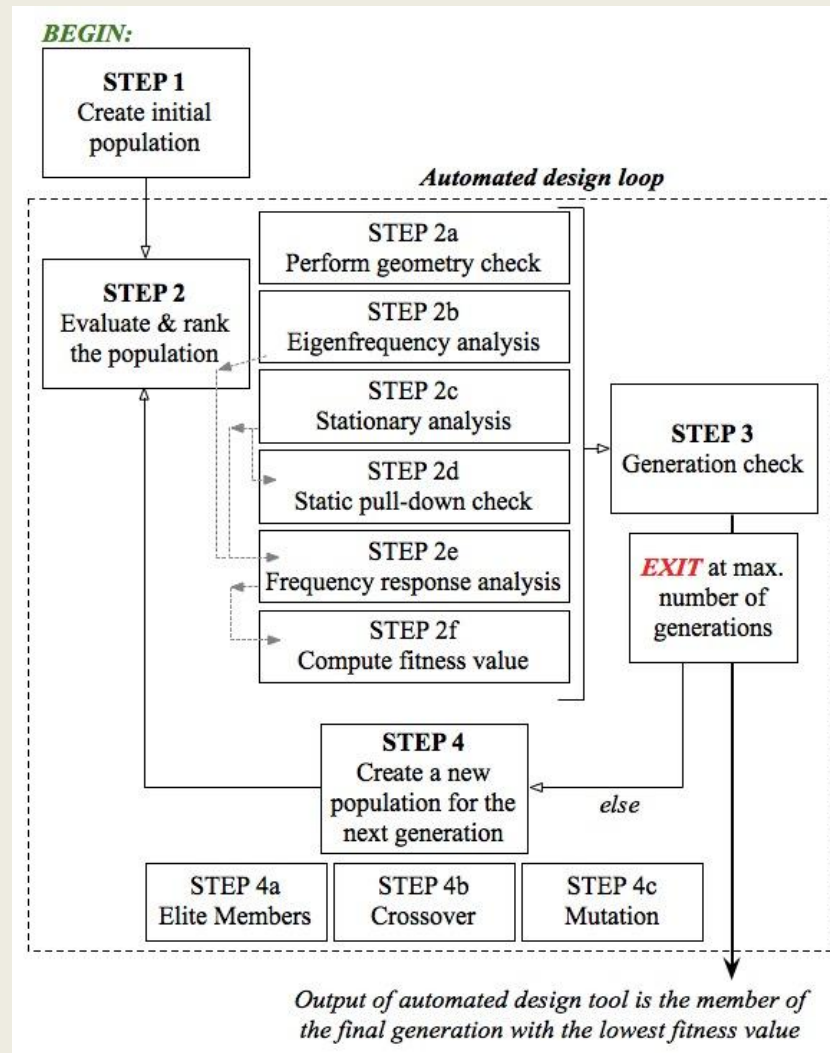
Design Goal

Determine a set of parameters to give the largest average *sensed* change in capacitance for a given accumulation of mass.

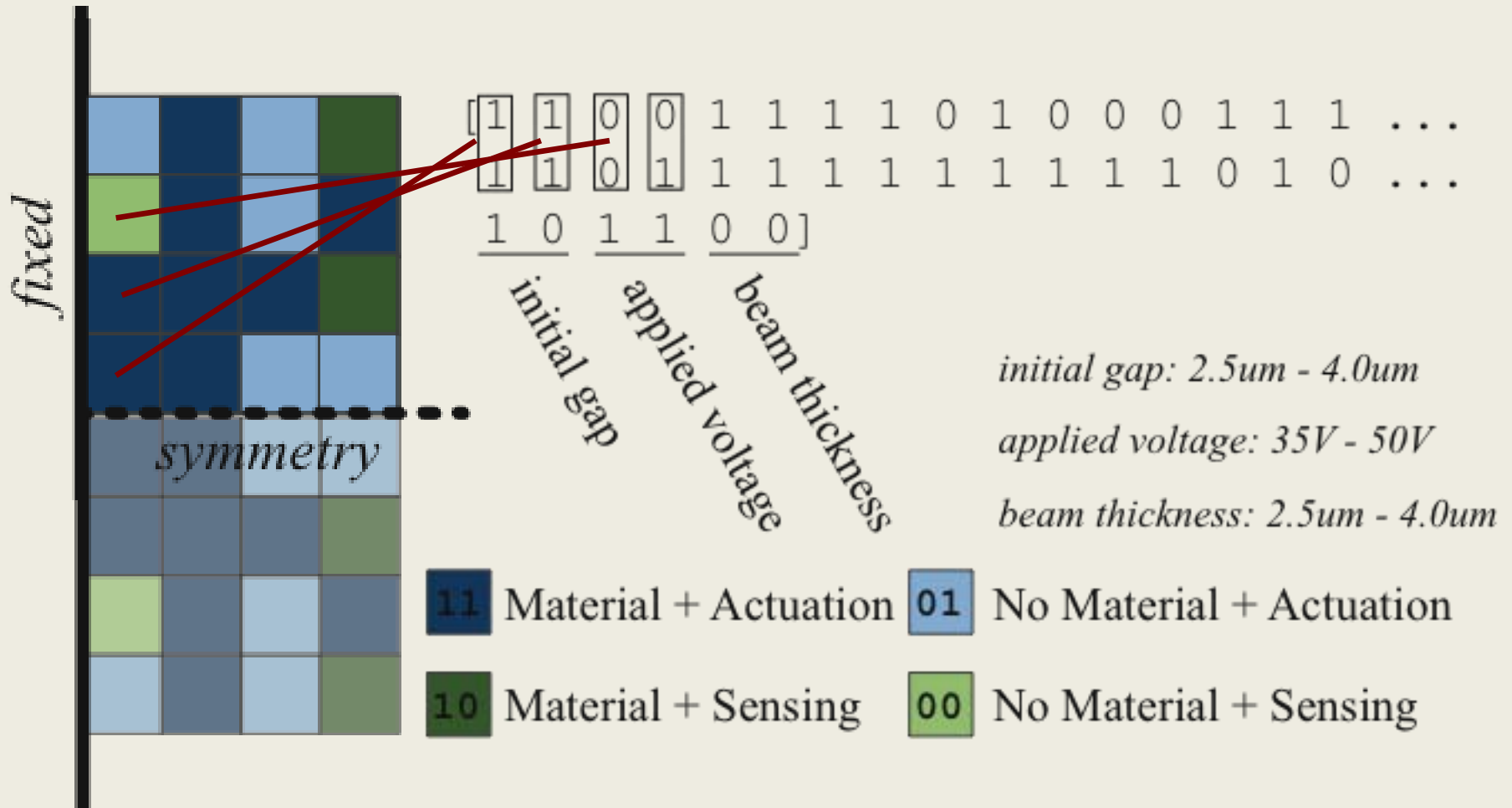
Parameters include:

1. Material distribution
2. Actuation electrode configuration
3. Sensing electrode configuration
4. Initial gap
5. Beam thickness
6. Actuation voltage

Automated Design Tool Process Flow



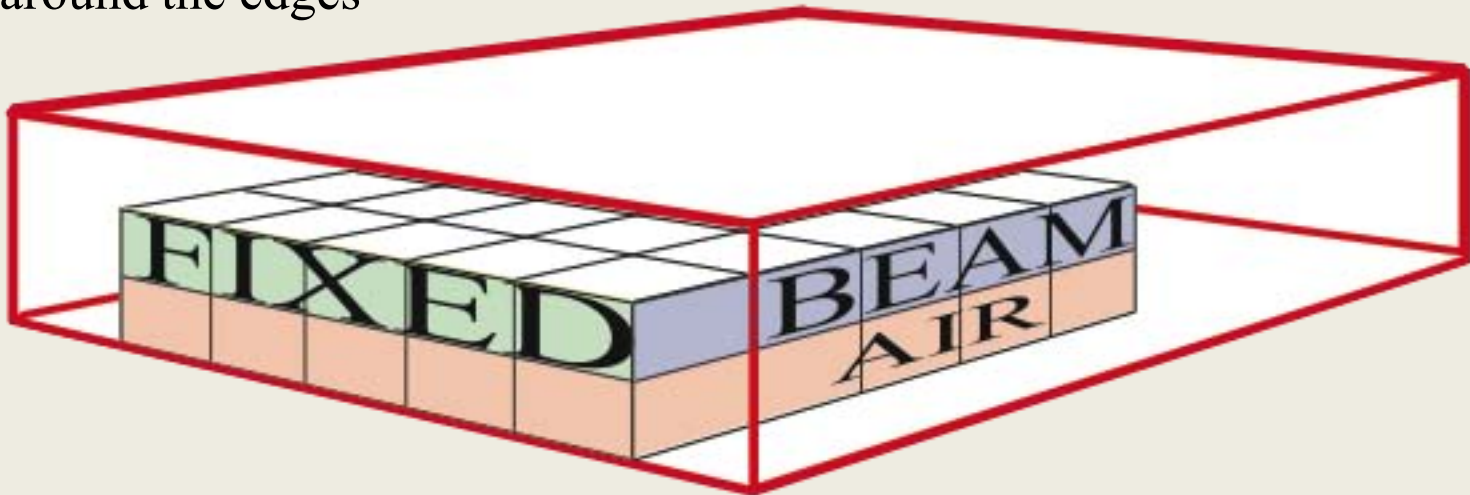
Configuration of Design Variables



Geometry

Geometry consists of 3 parts:

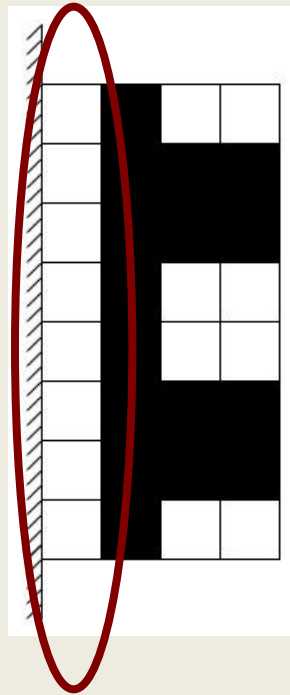
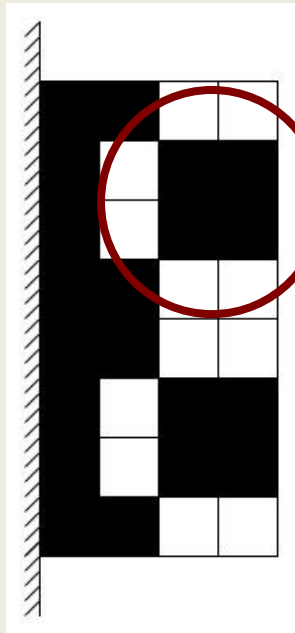
1. Regions representing the cantilever beam (fixed at left edge), referred to as “beam subdomains”
2. Regions representing the air gap beneath each beam region, referred to as “electrostatic subdomains”
3. A region of air encapsulating the device to examine the electrostatic field around the edges



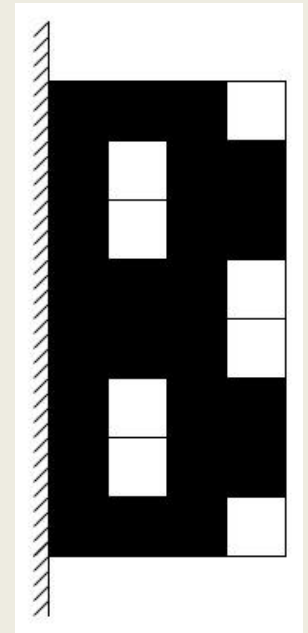
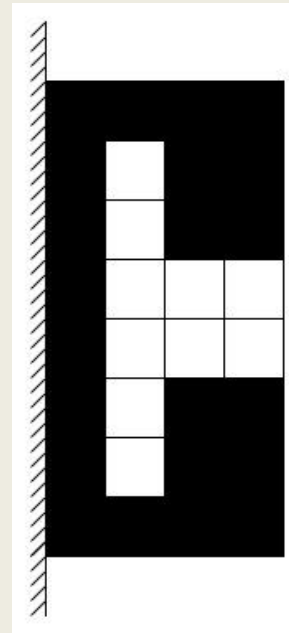
A geometry check is performed prior to any COMSOL solution.

Geometry

If a geometry is found to be invalid, a new – valid – geometry is generated to complete the population for that generation.



INVALID Geometries



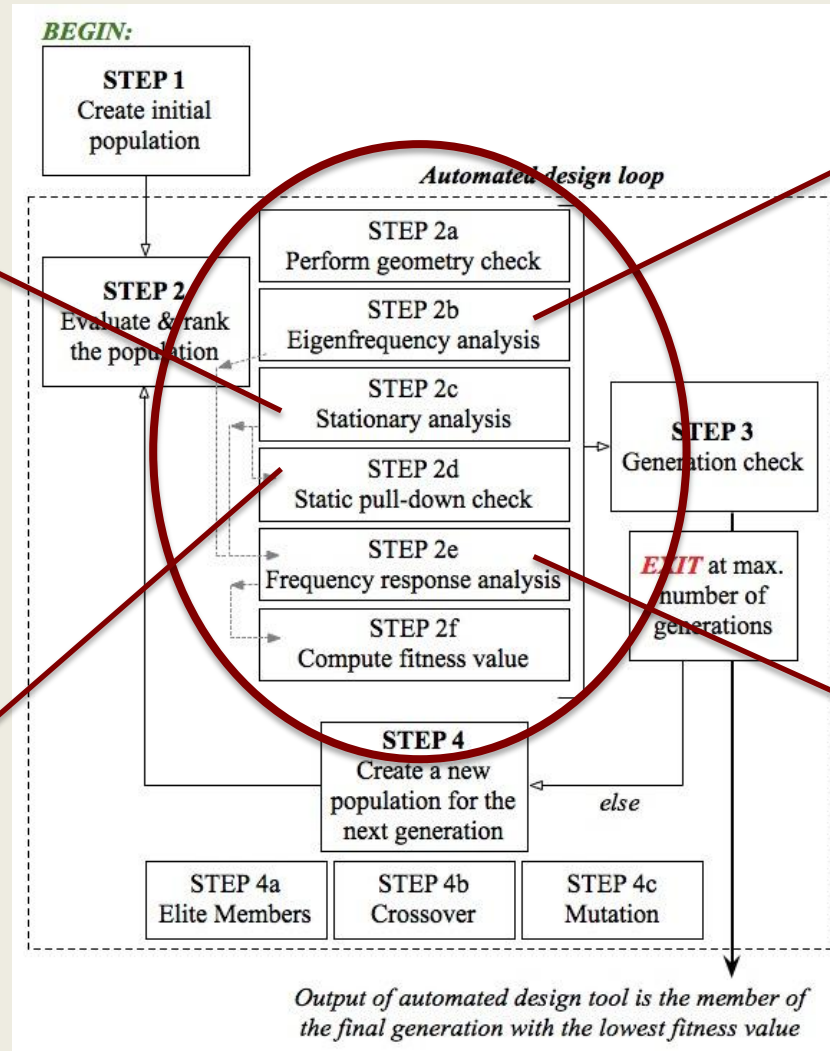
VALID Geometries

Fitness Computation

Compute the static deflection of the beam due to applied voltage

(SMSLD, ALE & EMES applications)

If the device experiences pull-down, the configuration is automatically assigned a high fitness value.



Compute the natural frequency of the beam (1) before mass accumulation and (2) after mass accumulation

(SMSLD application)

Compute the steady-state response of the beam (1) before mass accumulation and (2) after mass accumulation at *each natural frequency*

(SMSLD & MMFD applications)

Fitness Calculation

Fitness value (FV) = 2-point RMS averaged sensed change in capacitance for beam due to mass accumulation

- w = steady-state change in amplitude (output from COMSOL)
- A_{sensed} = electrode area assigned to sensing
- ϵ = permittivity of air
- $C_{sensed}(f_1)$ = avg. sensed steady-state change in capacitance
- $\Delta C_{sensed}(f_1)$ = avg. change in capacitance at frequency, f_1

$$C_{sensed(f_1)} = \frac{\epsilon A_{sensed}}{\left(\frac{\int w dA}{A_{sensed}} \right)}$$

$$\Delta C_{sensed(f_1)} = \left| C_{sensed(f_1)_{beam+mass}} - C_{sensed(f_1)_{beam}} \right|$$

$$FV = -\sqrt{\Delta C_{sensed(f_1)}^2 + \Delta C_{sensed(f_2)}^2}$$

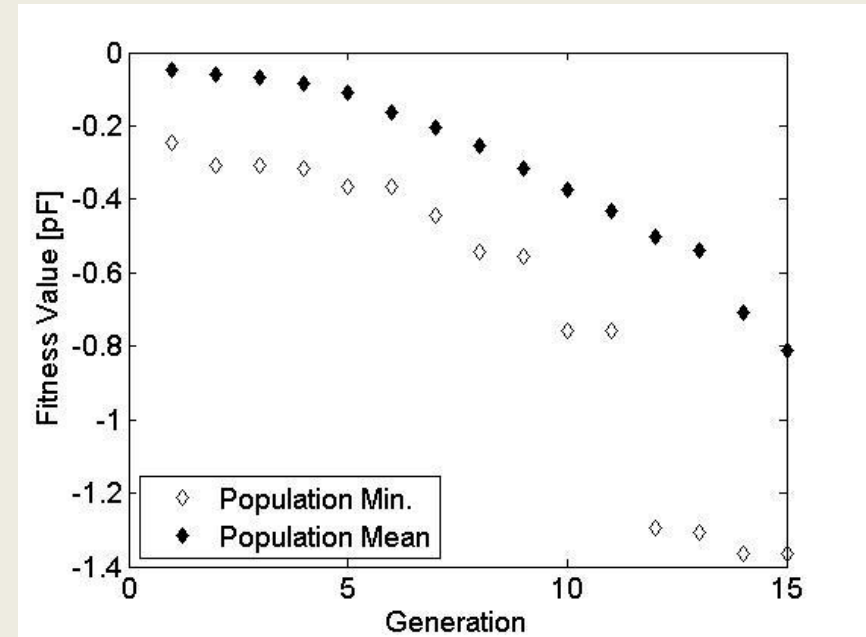
Results



initial gap: 3.5 μ m

applied voltage: 50V

beam thickness: 2.5 μ m



11 Material + Actuation **01** No Material + Actuation

10 Material + Sensing **00** No Material + Sensing

Looking ahead ...

- Improve practically of the design tool:
 - ◎ Constrain electrode design
 - ◎ Improved model for mass accumulation
 - ◎ Eliminate the need for coupling of the structural analysis and the electrostatic analysis
 - ◎ Develop an analytical method for approximating fringing forces
- Expansion of the design space:
 - ◎ Variable thickness values
 - ◎ Variable actuation voltages

Questions?