MEMS Process & Design Project
Term project presentation

2008.5.31

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Project Goal

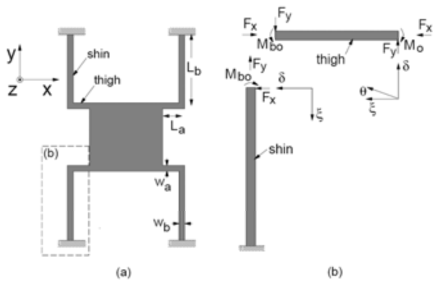
- Goal
  - Design and Fabrication of the *x/y* dual-axis comb-drive MEMS Resonator
- Design Constraints
  - 1. Chip size: 4 mm x 4 mm
  - 2. Lithography, etch constraints: minimum dimension (4 um line and space)
  - 3. Primary mode natural frequency: 5 kHz
  - 4. Secondary mode natural frequency: 5 kHz + 500 Hz (± 10 %)
  - 5. Actuation voltage: The lower, the better.

Spring Design (1)

- Clab-leg spring(1)
  - Good
    - Simple structure
    - Easy to design
  - Bad
    - Weak to stress
    - Tend to bend unexpected direction

Spring Design (2)

- Clab-leg spring (2)



Spring constant

X−direction

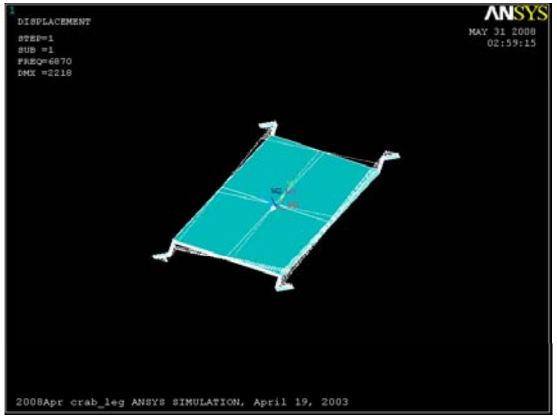
$$k_x = \frac{4F_x}{\delta_x} = \frac{Etw_b^3(4L_b + \alpha L_a)}{L_b^3(L_b + \alpha L_a)}$$

Y−direction

$$k_y = \frac{4F_y}{\delta_y} = \frac{Etw_a^3(L_b + 4\alpha L_a)}{L_a^3(L_b + \alpha L_a)}$$

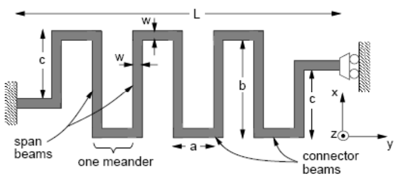
Spring Design (3)

- Clab-leg spring (3)



Spring Design (3)

- Serpentine spring



Spring constant

If b=c,
For odd n

X−direction

$$k_x = \frac{48EI_{z,b}}{a^2 n\left[(\tilde{a}+b)n^2 - 3bn + 2b\right]}$$

Y−direction

$$k_y = \frac{48EI_{z,b}\left[(\tilde{a}+b)n - b\right]}{b^2(n-1)\left[(3\tilde{a}^2 + 4\tilde{a}b + b^2)n + 3\tilde{a}^2 - b^2\right]}$$

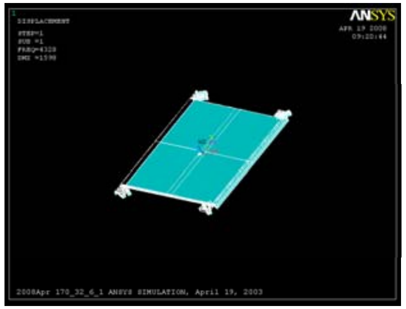
Spring Design (4)

- First spring design using the equation
  - Supposed Mass: 2mm * 2mm * 65um (6.058×10^{-7} kg)
  - N=5
  - Spring width = 4um
  - a=32um, b=170um

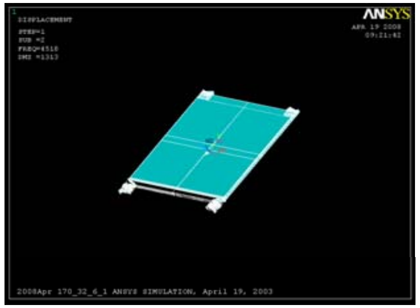
  - Calculated Spring constant
    - Kx=193.2 N/m
    - Ky=152.3 N/m
  - Calculated Resonate frequency
    - fx=5685 Hz
    - fy=5048 Hz

Spring Design (5)

- First simulation result



First mode :4327Hz



Second mode :4517Hz

Spring Design (4)

- Serpentine spring simulation result

	Calculated frequency	Simulated frequency	Error
First mode	5048 Hz	4327 Hz	15 %
Second mode	5685 Hz	4517 Hz	20 %

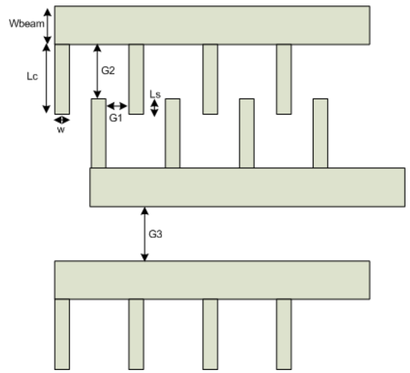
Comb Structure Design (1)

- Dual axis drive structure → less combs on each axis
- Need more comb or space
- Design more comb → reduce the comb finger width
- Reduce empty space → reduce space between comb support beam and support beam

- → Safety?

Comb Structure Design (3)

- Forces of Comb Drive structure



G_1=4um, Lc=15um, w=3um, G_2=12um

$$F_{tot} = F_1 + F_2 - F_3 = \varepsilon_0 \times h \times V^2 \times \left(\frac{n}{G_1} + \frac{w \times n}{G_2^{\,2}} - \frac{L}{2G_3^{\,2}} \right)$$

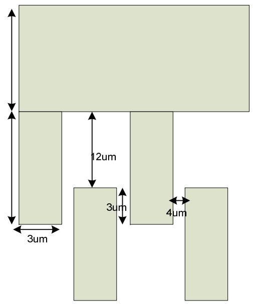
$$F_{tot0} = \varepsilon_0 \times h \times V^2 \times \left(\frac{n}{G_1} + \frac{w \times n}{G_2^{\,2}} - \frac{L_{beam}}{2G_3^{\,2}} \right)$$

$$= \varepsilon_0 \times h \times V^2 \times n \times \left(\frac{1}{G_1} + \frac{w}{G_2^{\,2}} - \frac{2(w+G_1)}{2G_3^{\,2}} \right)$$

$$L_{beam} \approx 2(w+G_1)$$

Comb Structure Design (2)

- Spring Constant of comb finger



Spring constant of a single comb finger

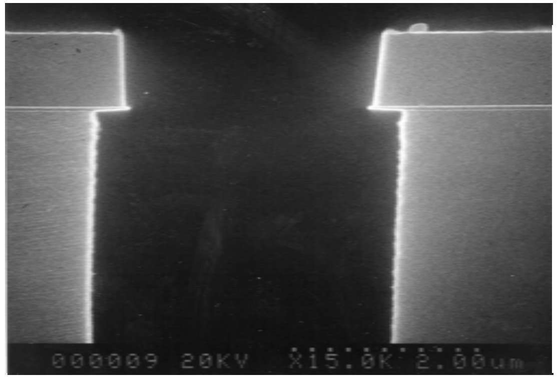
$$k = \frac{E \times h \times w^3}{4Lc^3} = \frac{169Gpa \times 65um \times (3um)^3}{4(15um)^3} = 2.190 \times 10^4 (N/m)$$

Force on a comb finger

$$F = 1/2 \times (\varepsilon_0 \times Ls \times h) \times \left(\frac{1}{(G_1 - x)^2} - \frac{1}{(G_1 + x)^2}\right) \times V^2$$

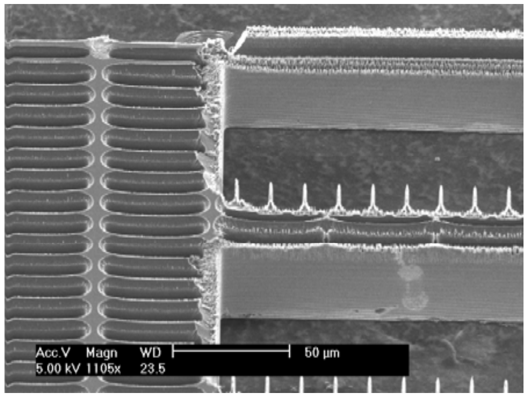
Fabrication error(1)

- Under-cut effect
  - Don`t consider



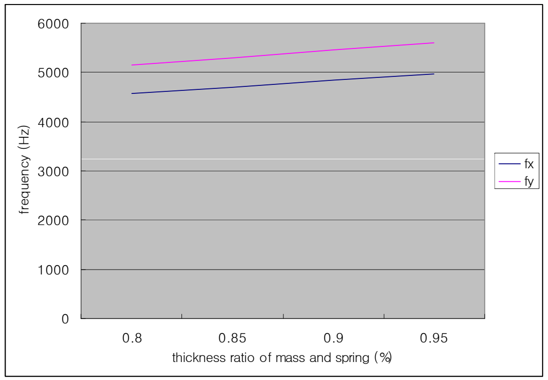
Fabrication error(2)

- Footing effect (1)
  - Different between mass and spring



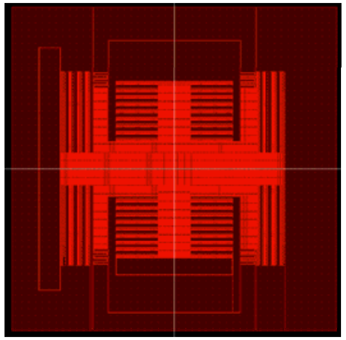
Fabrication error(3)

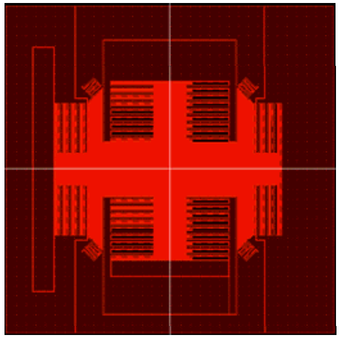
- Footing effect (2)
  - 80%~95% → safe



Final mask

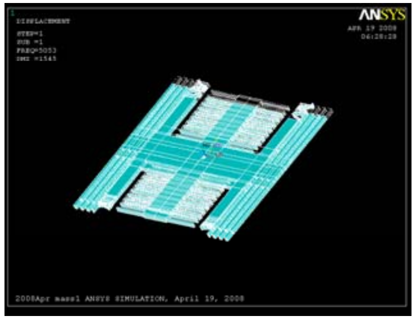
- Design #1
- Design #2



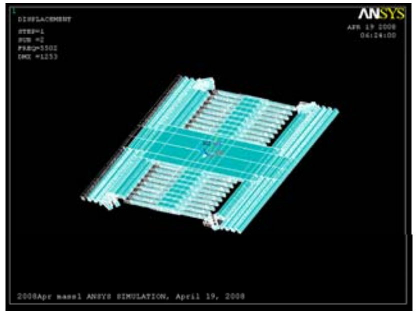


Simulation result(1)

- Design #1



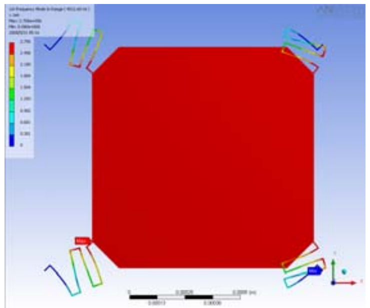
1st mode



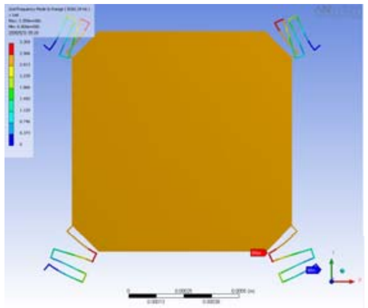
2nd mode

Simulation result(2)

- Design #3



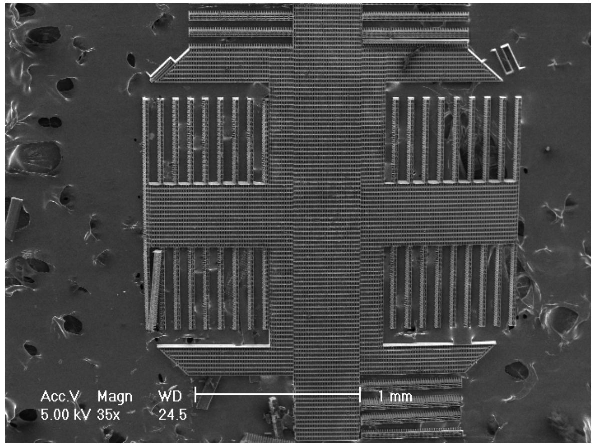
1st mode



2nd mode

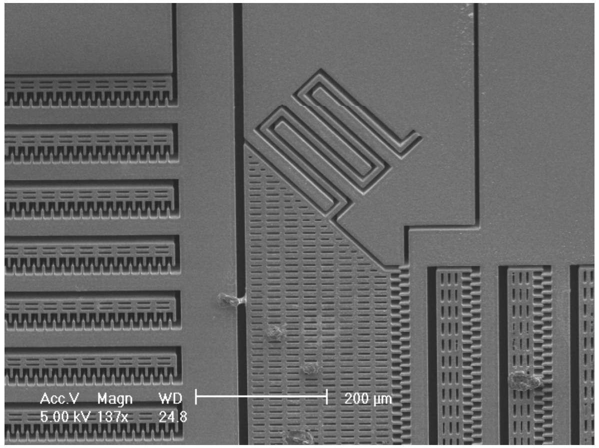
Fabrication Result(1)

- Backside picture of the whole structure



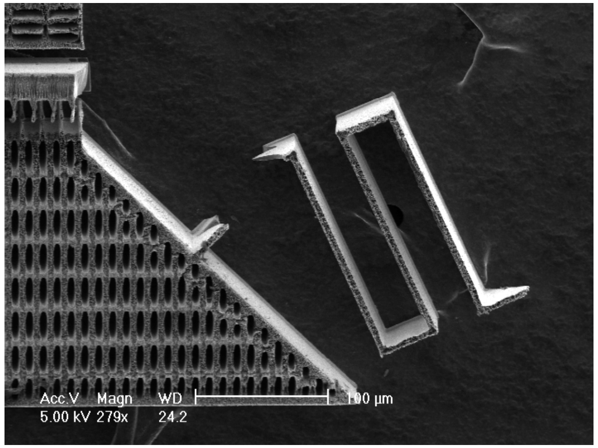
Fabrication Result (2)

- Front side of spring part



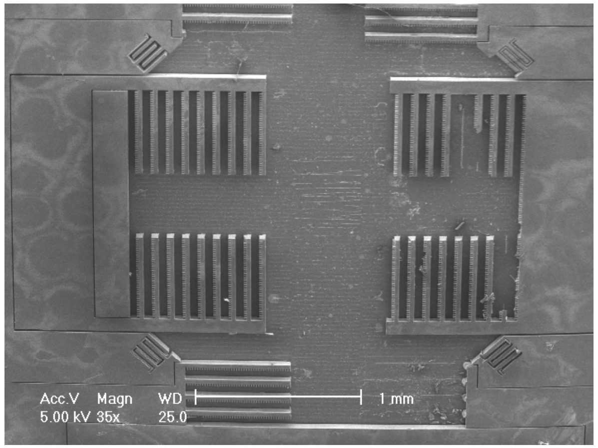
Fabrication Result (3)

- Backside picture of spring



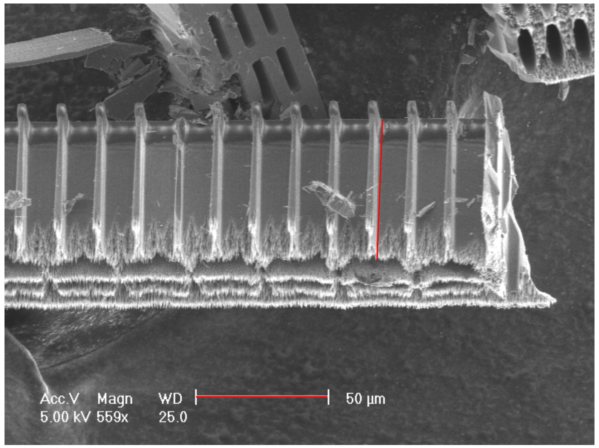
Fabrication Result (4)

- Substrate



Fabrication Result (5)

- Support beam



Evaluation result (1)

Evaluation result (2)

	1^{st} mode calculated frequency	2^{nd} mode calculated frequency	Calculated difference
Design #1	5749	5105	644
Design #2			
	1^{st} mode Simulated frequency	2^{nd} mode Simulated frequency	Simulated difference
Design #1	5053	5502	451
Design #2	4512	5030	518
	1^{st} mode measured frequency	2^{nd} mode measured frequency	Measured difference
Design #1	4500	4970	470
Design #2	4100	4600	500

Conclusion

- Use the serpentine spring
- Make 2 type of design
- Satisfy the project goal