

Lecture 3:

2005 Term Project Review

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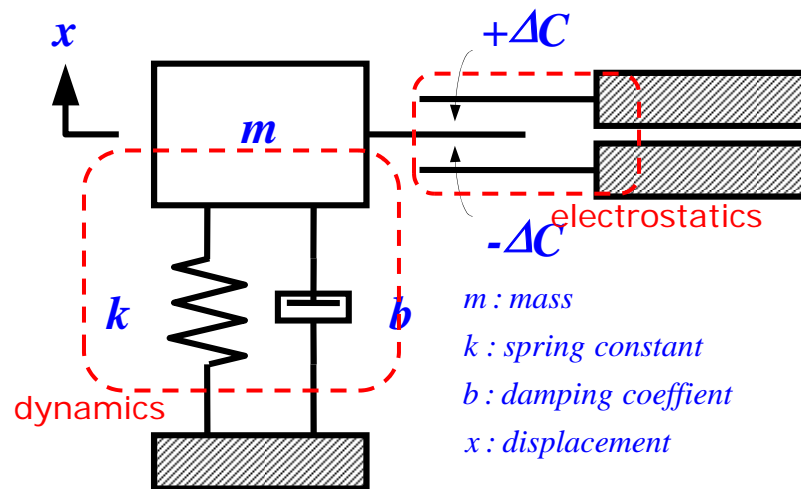
Project Goals & Design Constraints

- Design and fabricate a comb-drive type actuator
 - for large actuation distance
 - low-voltage
 - DC actuation or AC resonance at any natural frequency is possible
- Design Constraints
 - Die size: 4mm X 4 mm
 - Lithography, etch constraints: 4 um (line and space)
 - Minimize the footing phenomenon
 - Must put a ruler to measure the actuation distance
 - Must use less than 200 volts or so, due to limited supply and possible breakdown
- Project Goal
 - measure $\frac{\textit{maximum distance}}{\textit{applied voltage}}$
 - Maximize the ratio



Design Procedure Example

1. Die size & Core size
2. Decide 'maximum distance' and 'applied voltage'
3. Decide 'spring constant' and calculate 'capacitance'
 - Choose 'spring type' (fixed-end, guided-end, folded, folded-flexure)
 - Choose 'mass type' (comb-drive, parallel plate)
4. Draw layout & perform simulation
 - Cadence, ANSYS



$$F = kx$$

$$F = \frac{dW}{dx} = \frac{d}{dx} \left(\frac{1}{2} CV^2 \right) = \frac{1}{2} V^2 \frac{dC}{dx}$$

x : maximum distance

k : spring constant

W : Energy induced by electric field

C : capacitance

V : applied voltage



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2005 Design Summary

	#	1	2		3		4		5		6		7	8
	type	#1	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#1
spring design	spring type	folded spring	folded spring		folded spring		guided-end spring	folded-flexure spring	folded spring		serpentine spring		folded spring	folded-flexure spring
	spring constant [N/m]	7.34	10.4	7.3	-	-	8.51	2.23	-	-	32.03	-	93	5.07
Force	applied voltage [V]	28.4	10.8	10.65	44	30	40.6	20.8	14	30	15	15	39.7	20
	maximum displacement [μm]	15	18	15	15	10	33	15	20	20	25	15	10	10.5
comb design	Type	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive	comb-drive
	number of combs	1200	2600	2600	-	-	1280	320	4000	2500	1580	1580	4440	-
target	$\mu\text{m}/\text{V}$	0.53	1.67	1.41	0.34	0.33	0.81	0.72	1.43	0.67	1.67	1.00	0.25	0.53

result	$\mu\text{m}/\text{V}$	0.45 (10μm, 22V)	-	-	0.63 (15μm, 24V)	-	-	-	1.05 (10μm, 9.5V)	0.85 (20μm, 23.3V)	-	-	0.4 (10μm, 25V)	-
	actuation	o	o	x	o	x	x	x	o	o	x	x	o	x

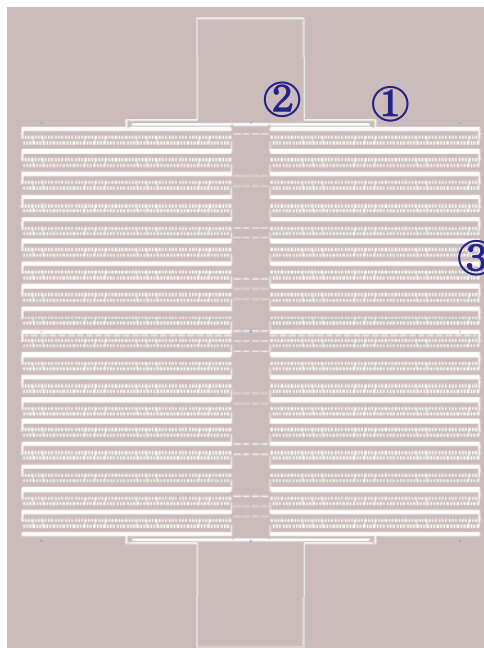


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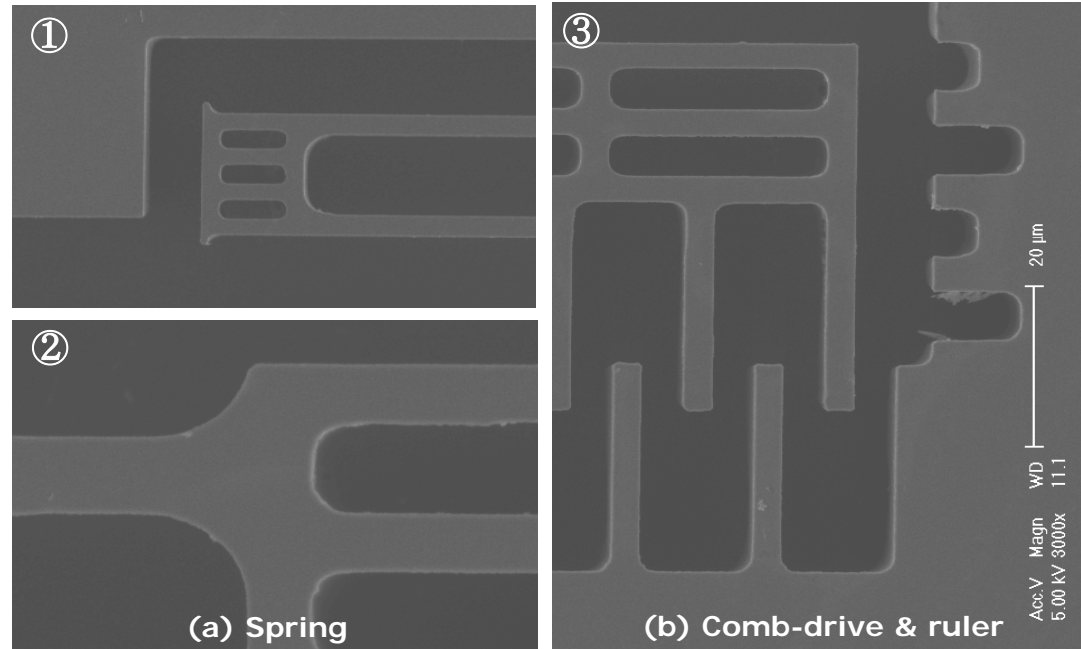
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Comb resonator design #3



Design Layout



Fabrication Result

- Comments
 - Folded spring design: spring length, spring gap
 - Etch hole size: 4 μm X 40 μm

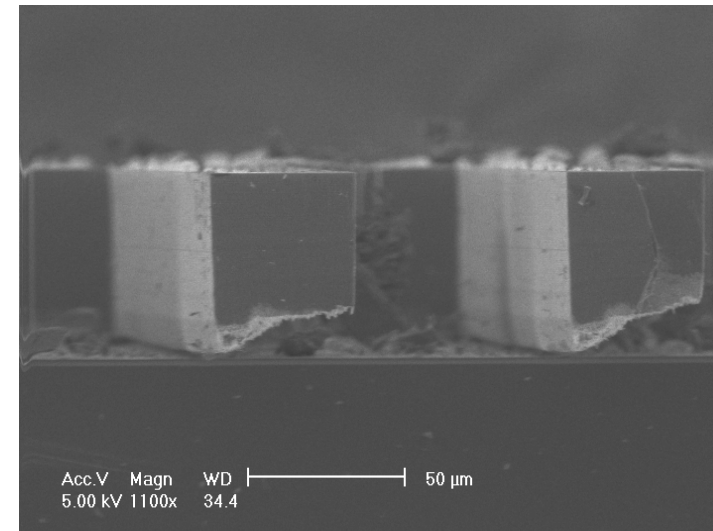
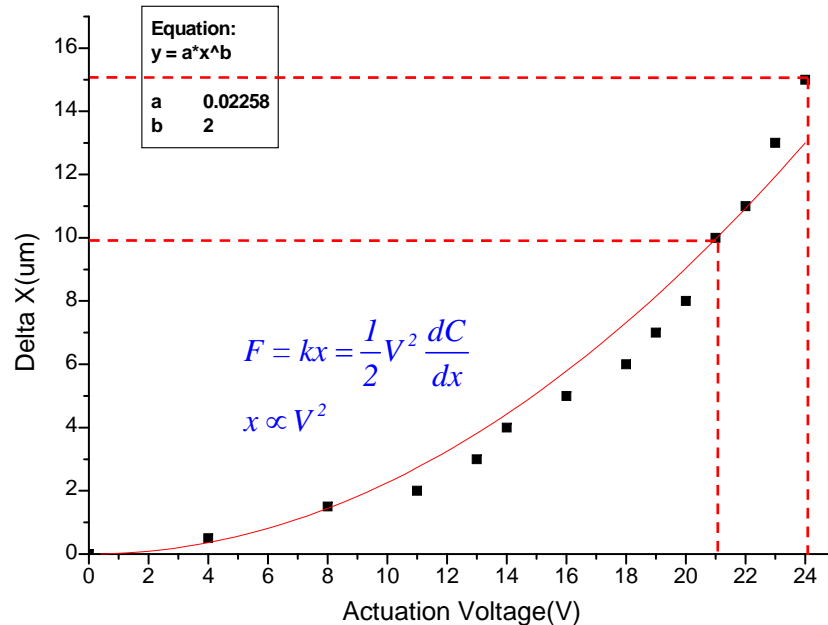


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Comb resonator design #3 (cont'd)



Fabrication Result (Footing effect)

- Measurement result
 - Measurement: 15um @ 24V (10um @ 21V)
 - Design: 15um @ 44V
 - Due to footing effect, decrease spring constant
 - Large displacement with high-voltage is easier

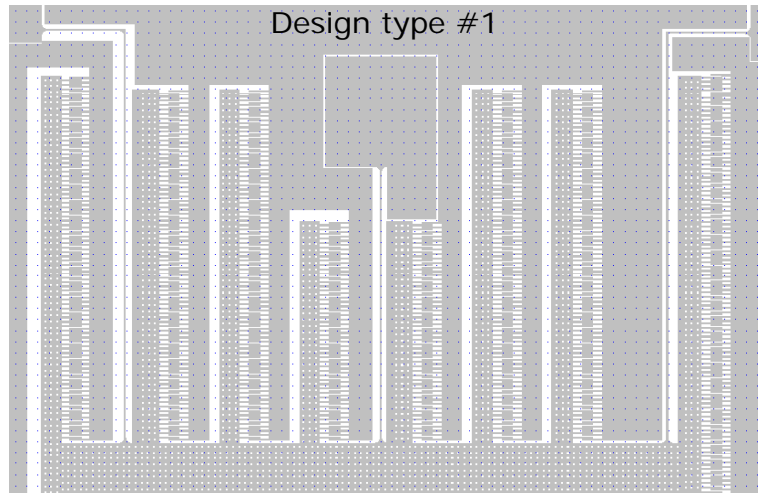


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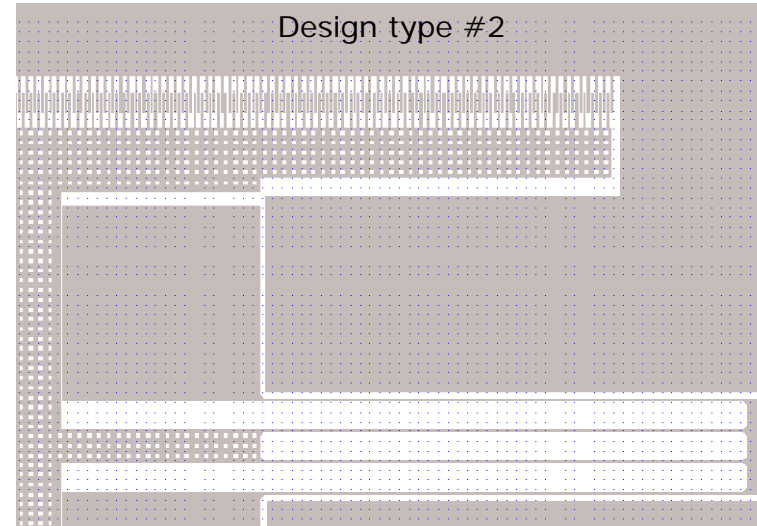
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Comb resonator design #4



- Comments
 - Spring design
 - Etch hole size: 10 um X 10 um
 - Ruler design error
 - Anchor design error

→ Release failure, not actuated



- Comments
 - Spring gap vs. other openings
 - Etch hole size: 10 um X 10 um
 - No ruler

→ Release failure, not actuated

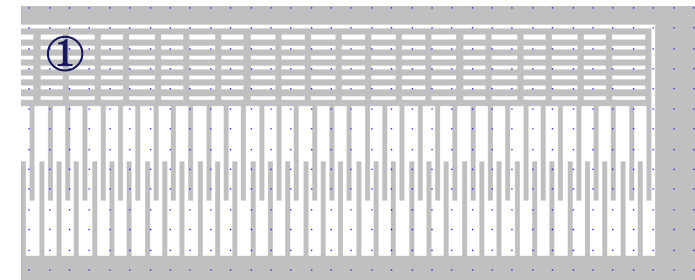
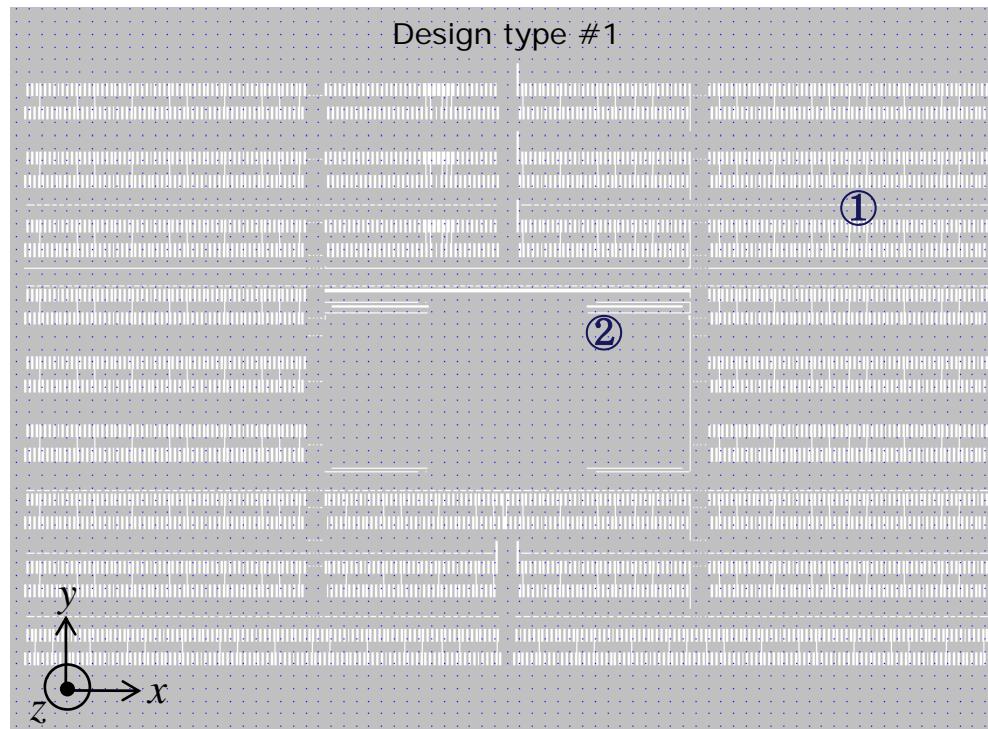


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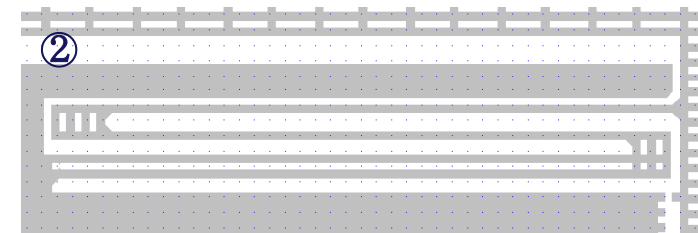
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Comb resonator design #6



Magnified view of comb-drive



Magnified view of spring

- Comments
 - 1) Comb-drive gap difference → Abnormal actuation in wrong axis (x-axis) & Spring breakage
Spring gap difference
 - 2) Etch hole size: 4 um X 8 um → Release failure, not actuated

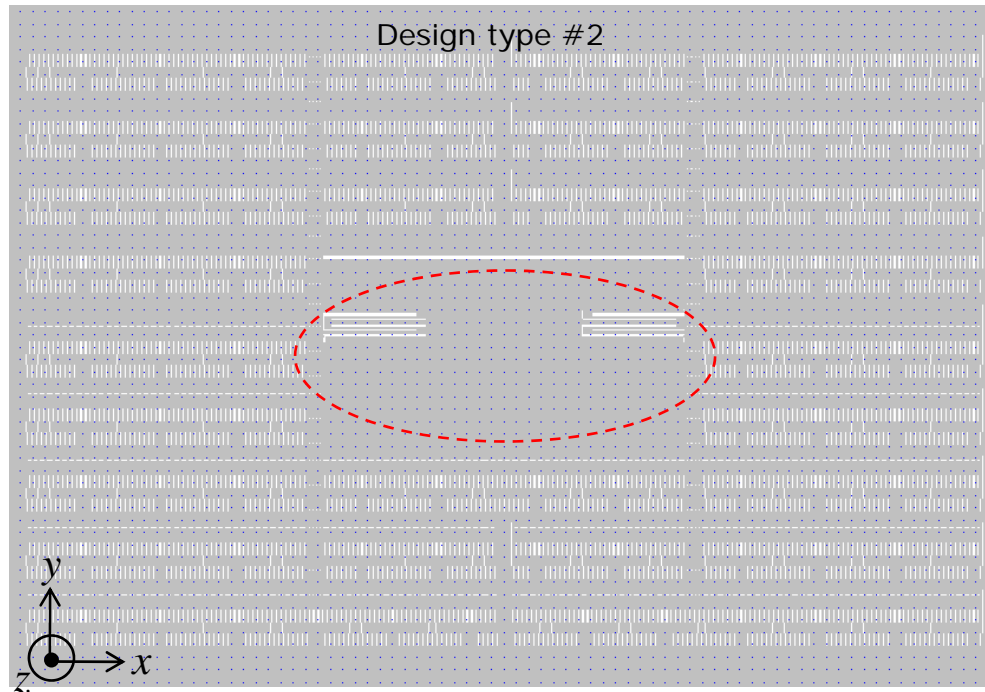


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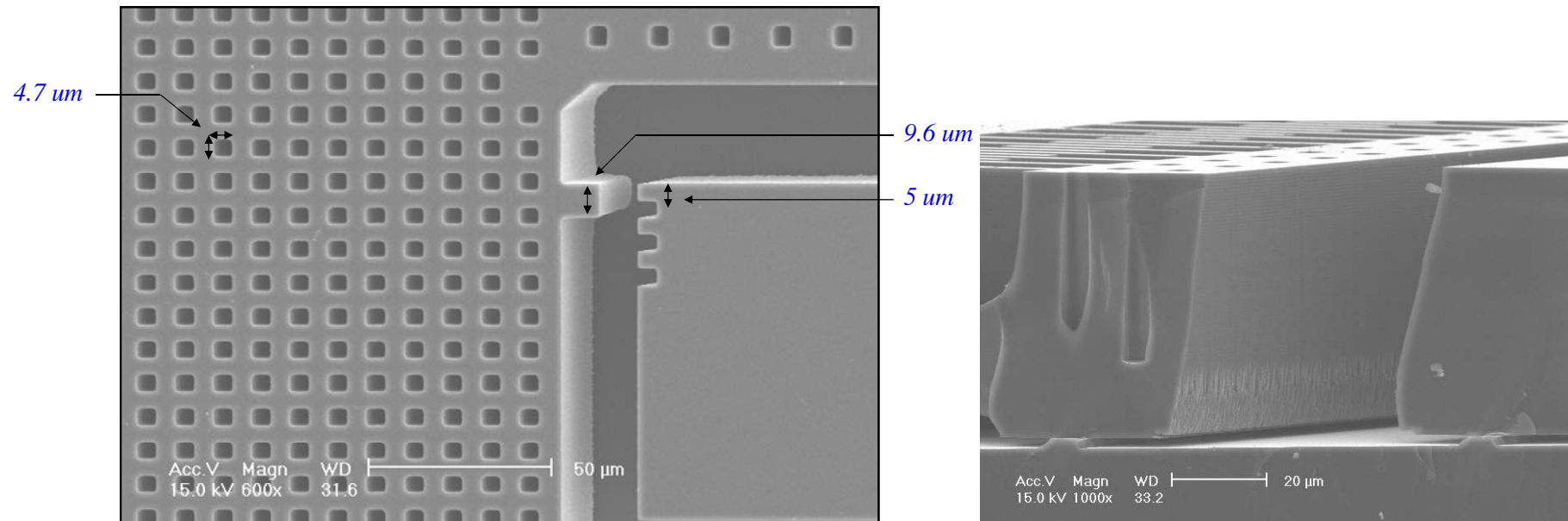
Comb resonator design #6 (cont'd)



- Comments
 - 1) Comb-drive gap difference & Spring gap difference
 - 2) Etch hole size: 4 μm X 8 μm
 - 3) Unstable design: yawing motion possibilities
 - 4) Unbalanced design: actuation in abnormal direction could occur



Comb resonator design #8



- Comments
 - Etch hole size: 5 μm X 5 μm
 - Release failure, not actuated



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Conclusions & Q/A

- Etch lag phenomenon
 - Etch hole design consideration
 - Gap variation issue
- Footing effect
- Release
 - Anchor design issue
- AC actuation
 - Larger displacement at lower voltage is possible

