Technology for Fabricating Dense 3-D Microstructure Arrays for Biomimetic Hair-like Capacitive Accelerometers

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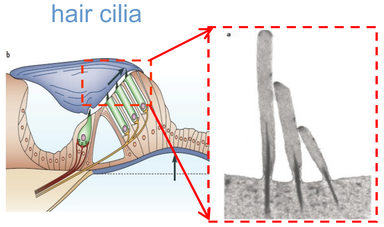
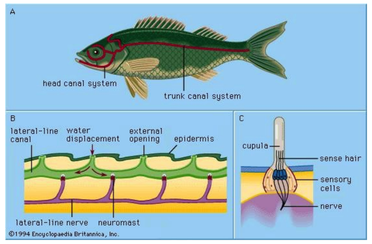
Biomimetic Hair Sensors

Cochlear in auditory system: hair cilia



Lateral-line sense hair in fish

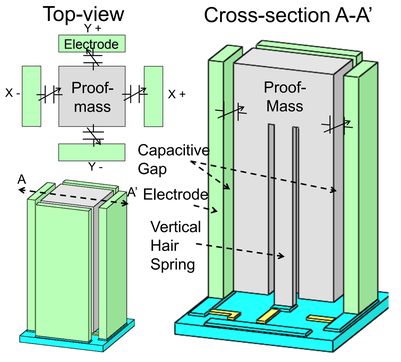


- High aspect-ratio biomimetic hair-like structures as a prototype for many MEMS devices
- 3-D fabrication technology to form dense array
- Built-in transduction mechanisms (e.g., capacitive)
- Sophisticated array signal processing

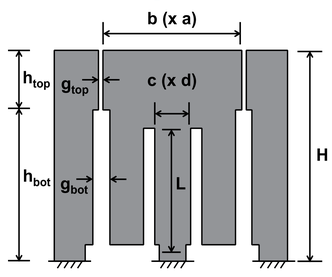
MEMS Accelerometer Design

- High capacitive sensitivity **(>0.1pF/g/mm²)**
- Low mechanical Brownian noise **(<1μg/√Hz /mm²)**
- Large bandwidth
- Great dynamic range **(μg to 1000 g)**

Single Hair Accelerometer



Critical Design Parameters



$$\frac{\Delta C}{Accel.} = \frac{1}{2}\varepsilon \times (a \times H) \times \frac{abH}{dc^3 / L^3} \times \frac{1}{g_0^2}$$

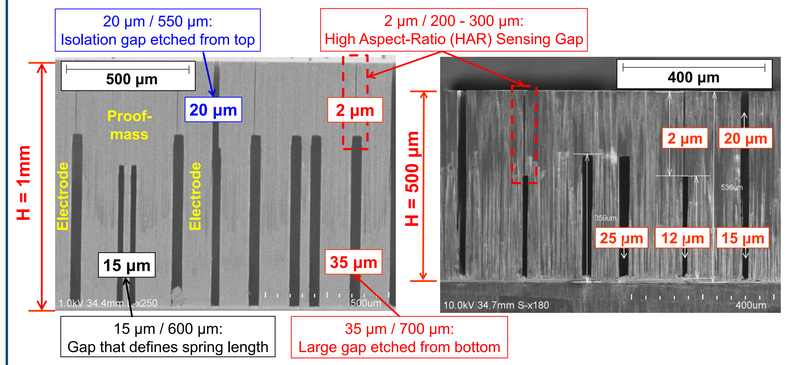
$$BNEA = \sqrt{\frac{4k_B TD}{M^2}} = \sqrt{\frac{4k_B T\omega_0}{MQ}} \propto \frac{1}{gap^{3/2}}$$

1) Large Proof-mass
2) Narrow capacitive gap
3) Modulated dimensions

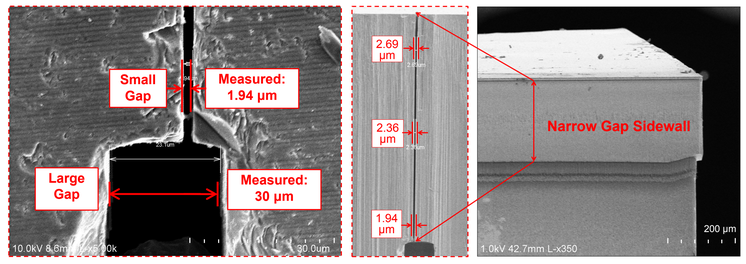
CMOS Compatible Fabrication

- High Aspect Ratio DRIE
- Au-Si eutectic bonding
- Integrated Electrical Connections
- CMOS compatible dry release

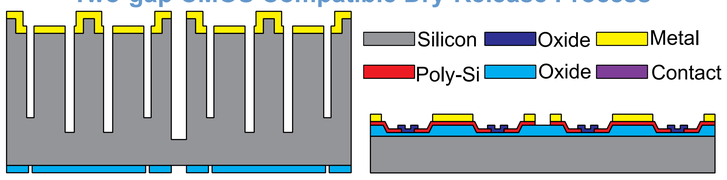
SEM Cross-Section of Hair Accelerometers



High aspect-ratio Narrow Gap 2μm / ~250μm

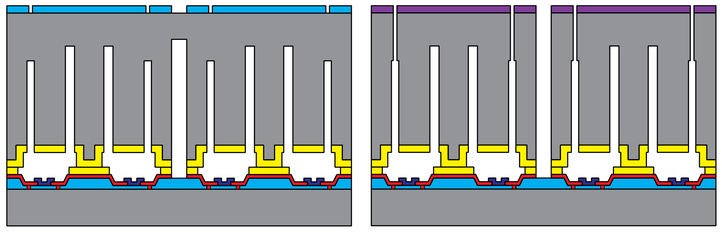


Two-gap CMOS Compatible Dry-Release Process



(a) Two-sided DRIE pattern and etch. Deposit bonding metal.

(b) Pattern passivation, electrical interconnect.



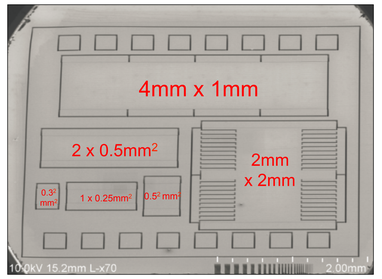
(c) Si-Au eutectic bond at 400C to anchor the hair spring/mass.

(d) Ultra high aspect-ratio DRIE to define the narrow 2μm gaps.

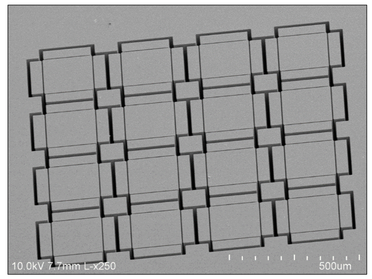
Electromechanical Testing Results

- Wide range of device performance is achieved

Different Hair Accel. Designs

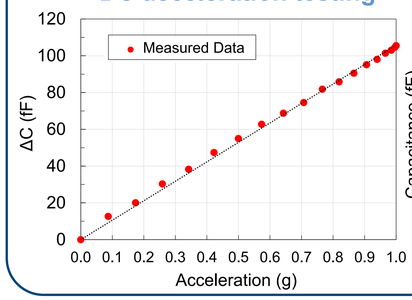


Identical Hair Arrays

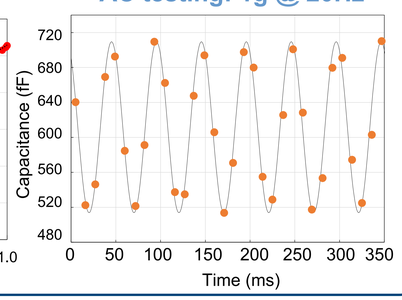


Height	Device Footprint		Spring	Gap	Simulated Sensitivity			Measured Sensitivity	
H	a	b	k	g_0	C_0	ΔC/g	Frequency	C_0	ΔC/g
1 mm	4 mm	1 mm	$2k_0$	2.5 μm	4.080 pF	156 fF/g	1.256 kHz	3.187 pF	105 fF/g
1 mm	2 mm	500 μm	$2k_0$	2.5 μm	2.187 pF	19.2 fF/g	2.512 kHz	1.478 pF	12.46 fF/g
1 mm	500 μm	500 μm	k_0	2.5 μm	510 fF	2.40 fF/g	3.553 kHz	728 fF	1.33 fF/g
1 mm	300 μm	300 μm	k_0	2.5 μm	305 fF	0.52 fF/g	5.921 kHz	257 fF	0.36 fF/g
Spring: c ≈ 35 μm, d ≈ 45 μm, L = 600 μm									

DC acceleration testing



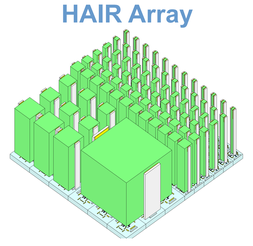
AC testing: 1g @ 20Hz



Conclusions

By taking advantage of high aspect ratio DRIE, we fabricate a new class of high performance hair-like 3-D MEMS accelerometer and dense arrays. We believe this technology can benefit many miniaturized MEMS transducers arrays research.

HAIR Array



Acknowledgements

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