Vertical Micro-probe Design Based on the EFAB^{TM} Micro-Fabrication Process

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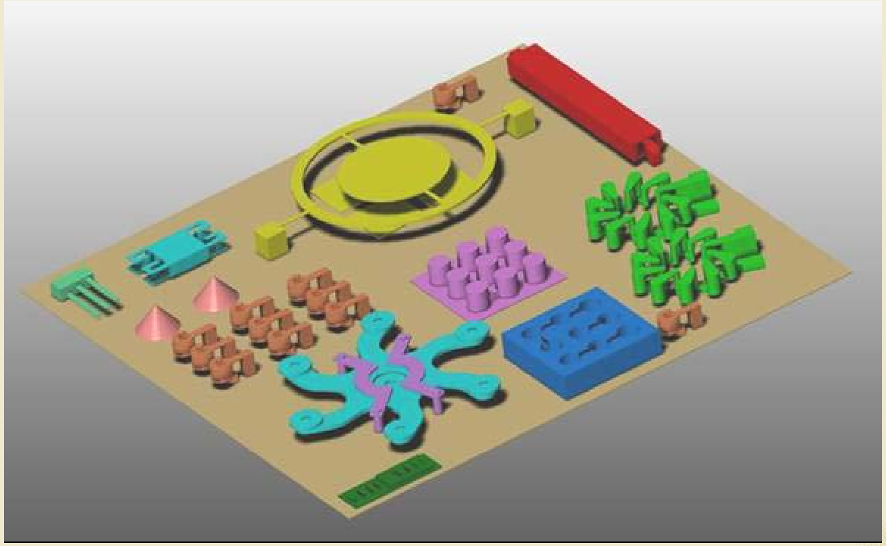
EFAB™ Micro-Fabrication Process

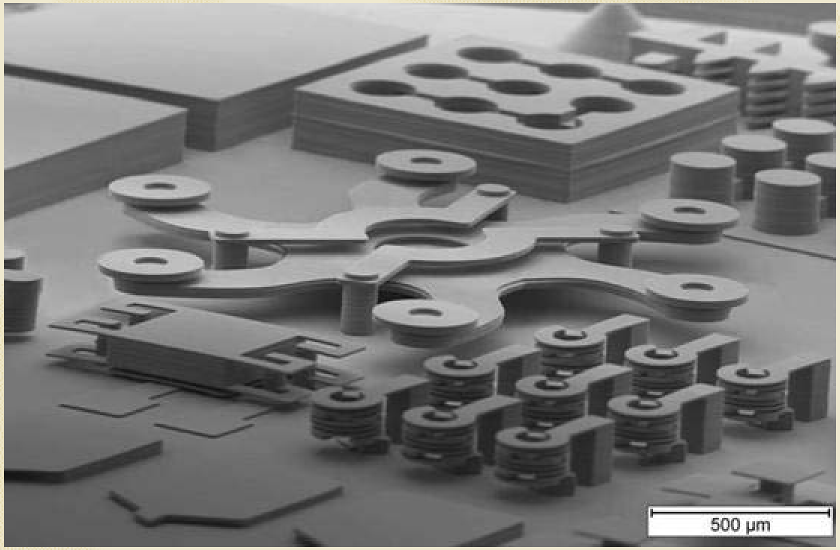
- Micro-fabrication process based on multi-layer electro-deposition of metals using proprietary selective deposition techniques
  - Capable of producing arbitrary 3-D shapes with no limitation in the number of layers
  - Capable of incorporating 3-D geometrical effects to improve device functionality and performance
  - Capable of generating devices directly from 3-D CAD models

EFAB^{TM} Design Flow

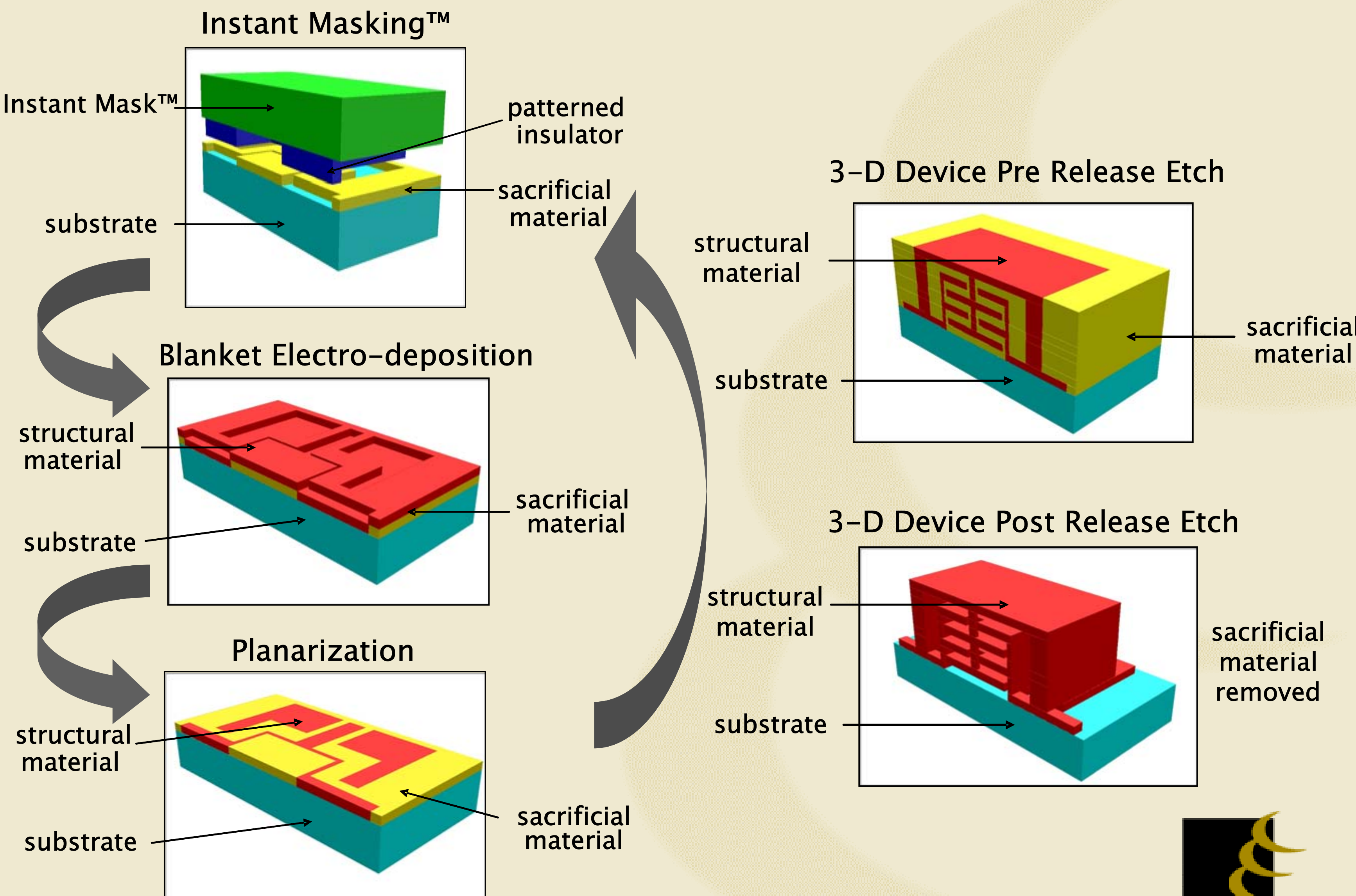
3-D CAD model



3-D Micro-devices



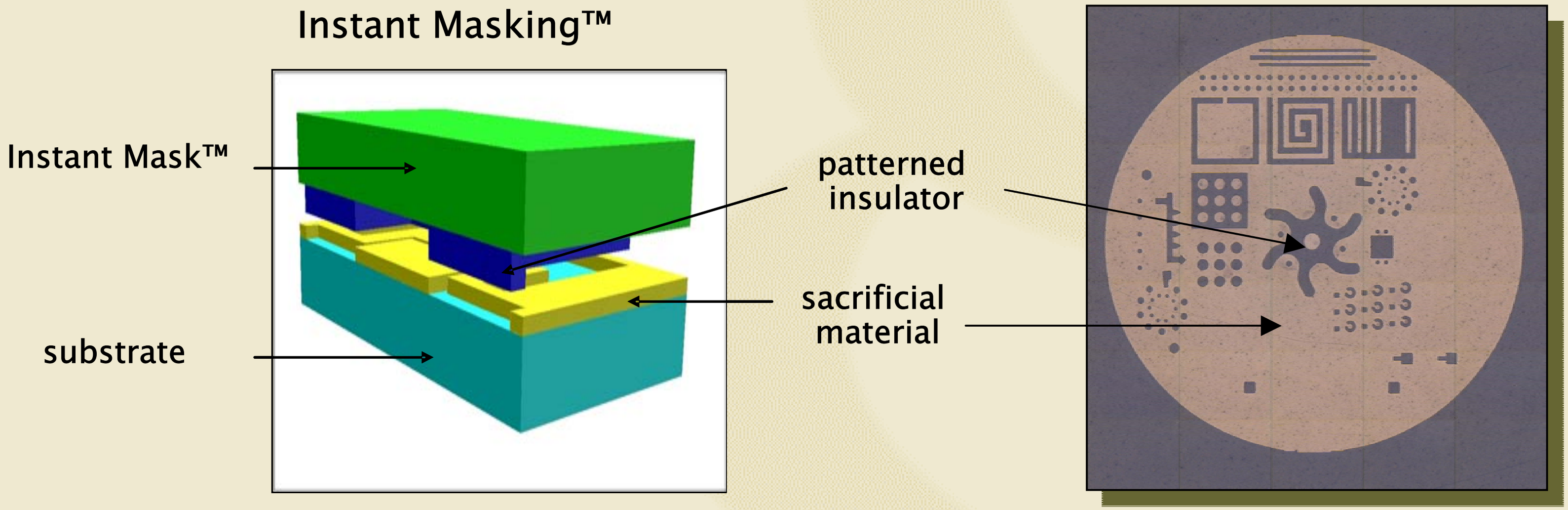
EFAB™ Process Flow



Instant Mask™

- Conformable insulating material patterned with apertures and electrode
- Photolithographic processing performed completely separate from the device building process creating improving speed, efficiency, and cost-effectiveness

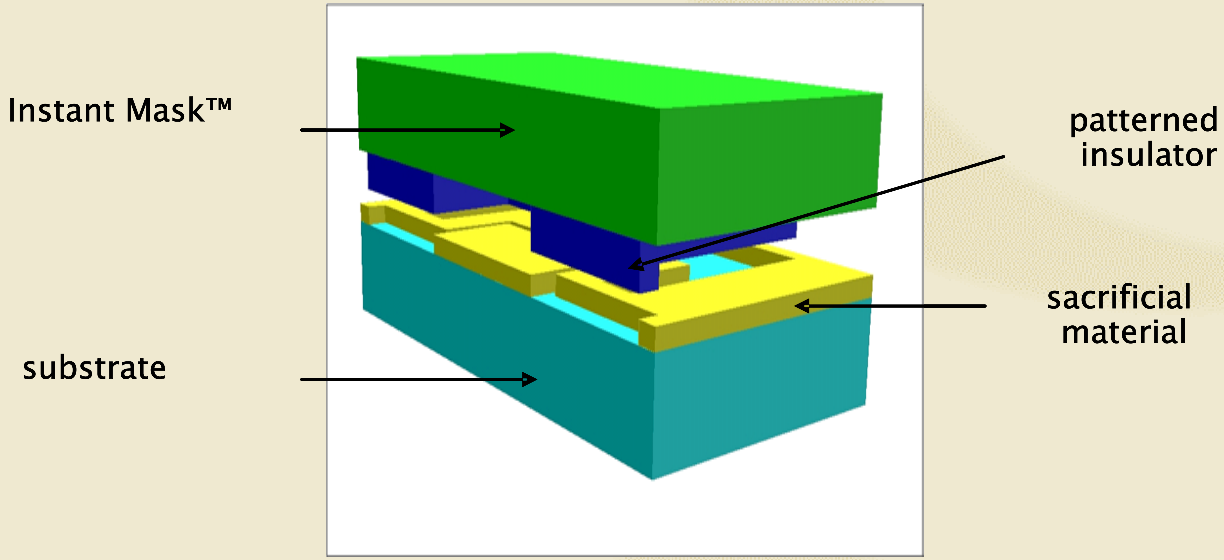
Instant Masking™



Step 1: Instant Masking™

- Instant Mask™ mated with substrate inside tank containing electro-deposition bath for 1st material
- Application of current selectively deposits first material within regions defined by patterned insulator

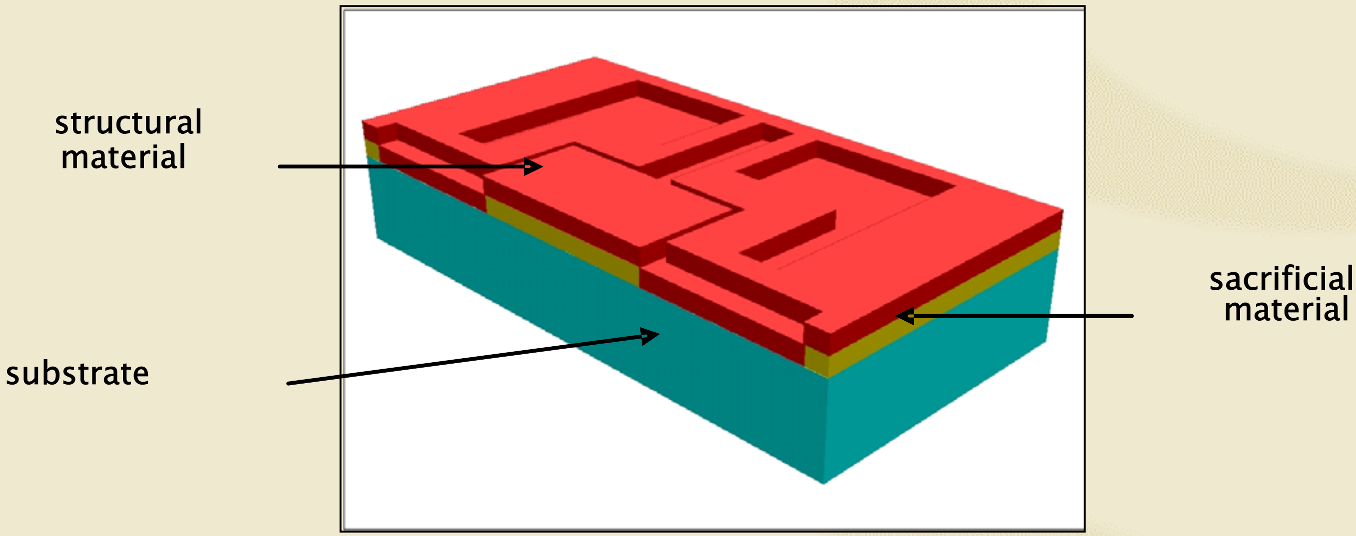
Instant Masking™



Step 2: Blanket Electro-Deposition

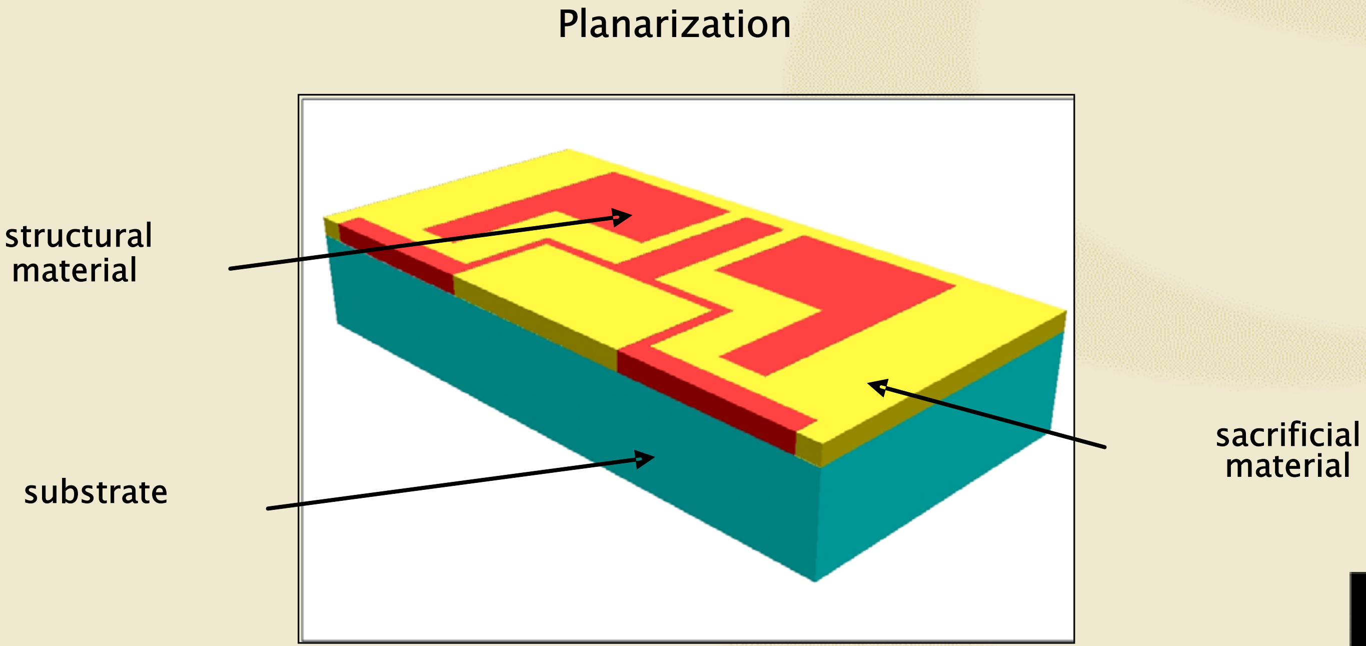
- After cleaning, substrate with 1st material transferred to second deposition tank containing electrodeposition bath for 2nd material
- Application of current deposits 2nd material over 1st material and substrate

Blanket Electro-deposition



Step 3: Planarization

- Substrate with 1st and 2nd materials transferred to planarization station for mechanical or chemical-mechanical polishing
- Establish precise vertical (Z) dimensions



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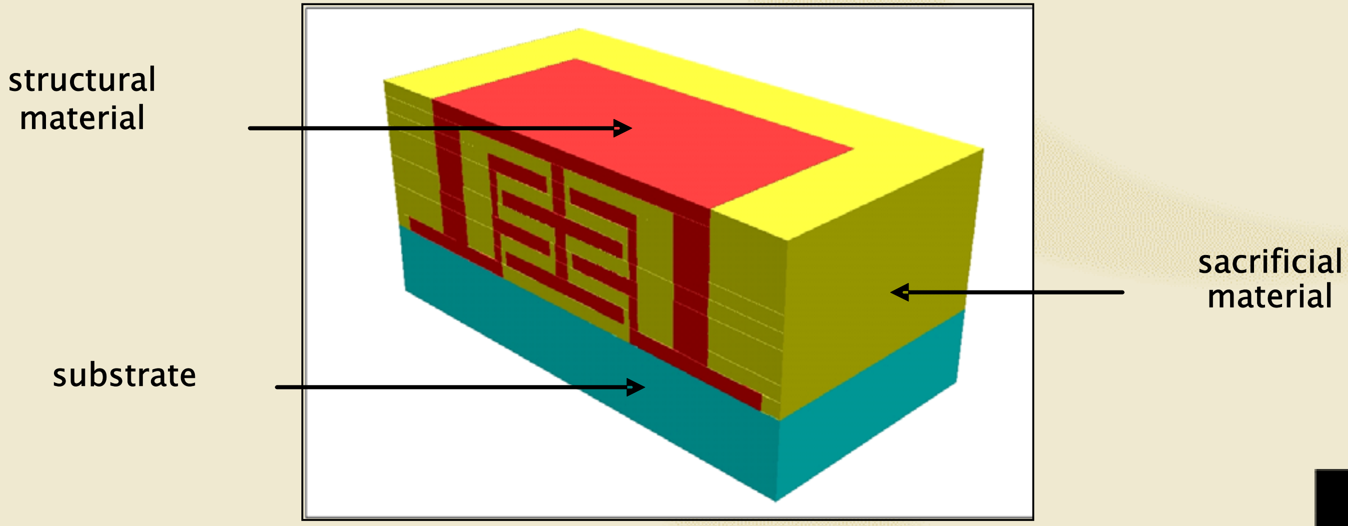
3-D Device Pre-Release Etch

- Instant Masking™, blanket electro-deposition and planarization repeated for all layers in device
- Layers registered via machine vision and aligned with respect to the substrate to provide for non-accumulating layer registration

3-D Device Pre Release Etch



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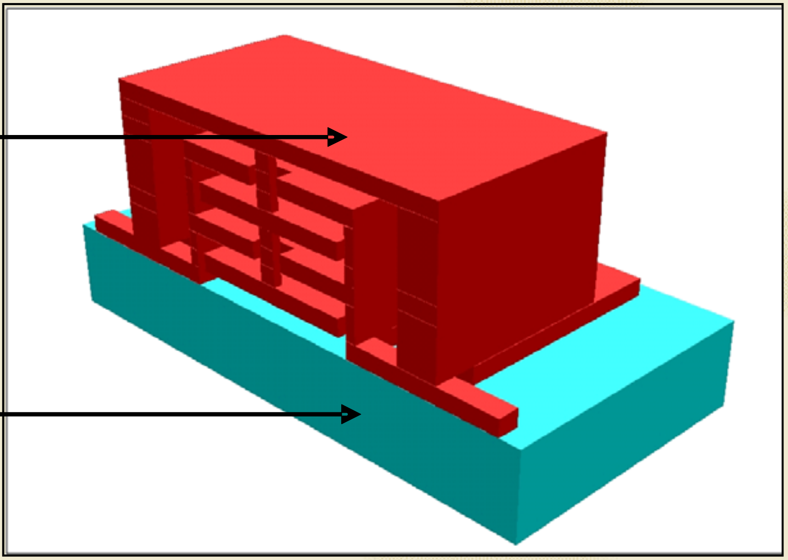
3-D Device Post-Release Etch

- Sacrificial material removed by chemical etching
- Etching selectivity: >500:1
- Etching rates: theoretically 100s μm/h

3-D Device Post Release Etch



Process Specifications

- Layer thickness:
  - Currently 2-10 μm; potential for 1-15 μm dimensional tolerance of +/- 0.3 μm non-accumulating; potential for +/- 0.1 μm
- Layer-to-layer registration:
  - Currently +/- 1.5 μm non-accumulating; potential for +/- 0.5 μm
- Minimum feature size: line width and space
  - Currently 20 μm; potential for 5-10 μm
- Substrate sizes:
  - Prototyping: 21 mm
  - Volume: 100 mm Q3 2003
  - Volume: 200 mm coming 2004

EFAB™ Structural Materials

	Nickel (Ni)	Silver (Ag)
Chemical composition	> 99.5% Ni	
Modulus of elasticity (GPa)	150–200	
Poisson's ratio	0.31	
Yield Strength (MPa)	> 800	
Tensile Strength (MPa)	> 800	
Stress gradient (MPa/μm)	< 60	
Fatigue life (s)	infinite @ < 100 MPa	not yet characterized
Inter-layer adhesion (shear)	> 200 MPa	
Thermal expansion coefficient (10^6/K)	13.4	
Thermal conductivity (W/m.K)	90	
Heat capacity (J/kg.K)	444	
Electrical resistivity (Ω.m)	6.84×10^{-8}	
Inter-layer contact resistance (Ω)	< 5 μΩ (10^4 μm^2)	

Values in bold font have been measured. Values in regular font are estimates.

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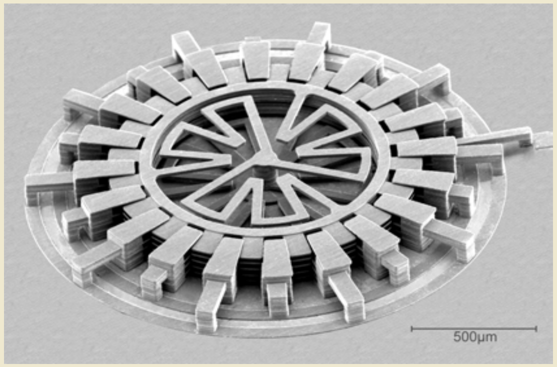
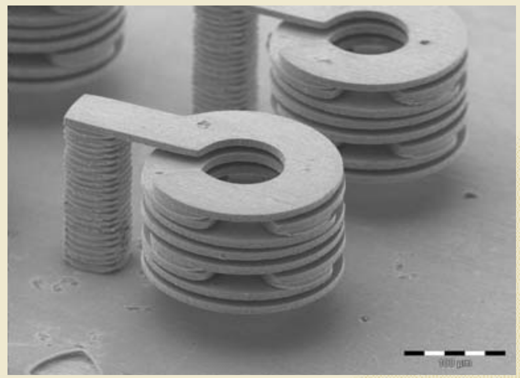
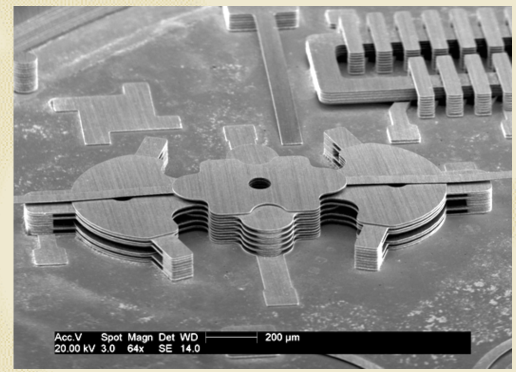
EFAB™ Substrates

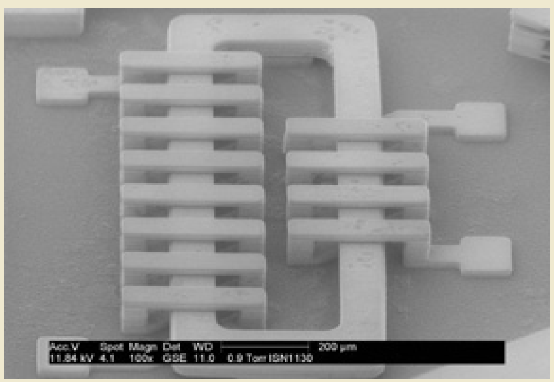
	Alumina	Nickel (Ni)
Size Prototyping production	19-mm diameter 200-mm diameter	21-mm diameter 200-mm diameter
Chemical composition	99.7 % Al_2O_3	100% Ni
Modulus of elasticity (GPa)	370	206
Poisson's ratio	0.2	0.31
Thermal expansion coefficient (10^6/K)	6.70 @ 20^0 C	13.4 @ 20^0 C
Thermal conductivity (W/m.K)	34.7	90
Heat capacity (J/kg.K)	not available	444
Electrical resistivity (Ω.m)	1.00×10^{14}	6.84×10^{-8}
Dielectric constant	9.9	not applicable

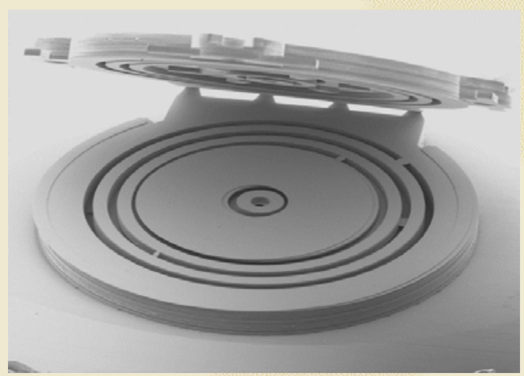
Examples of Arbitrary 3-D Shapes

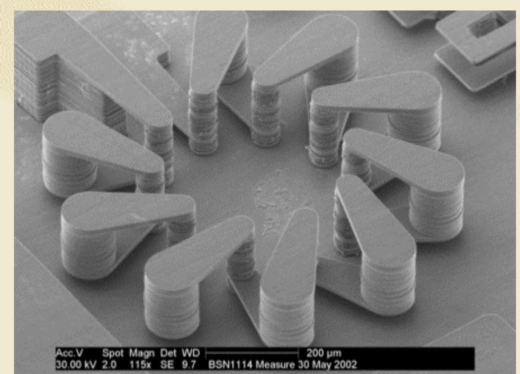












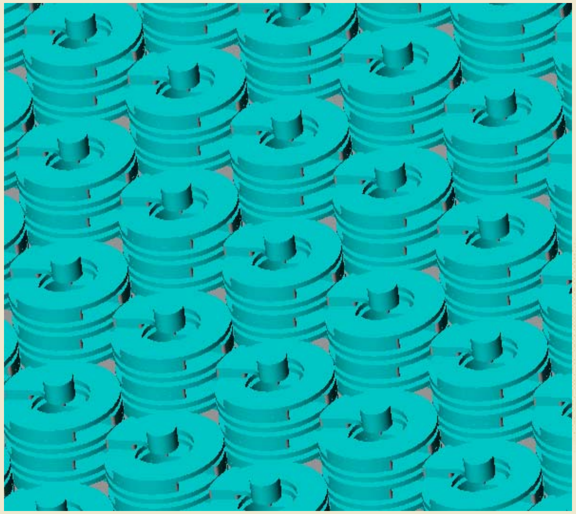
EFAB™
Vertical Micro-probes

- Small footprints and small pitch for large, customized micro-probe array patterns on custom substrates
- Highly functional mechanical/electrical designs to allow optimal contact force, contact resistance and current carrying capacity
- Tight dimensional tolerances to compensate for topology differences across wafer and increase fatigue life
- Higher performance at high-frequency operation due to shorter, less inductive probes

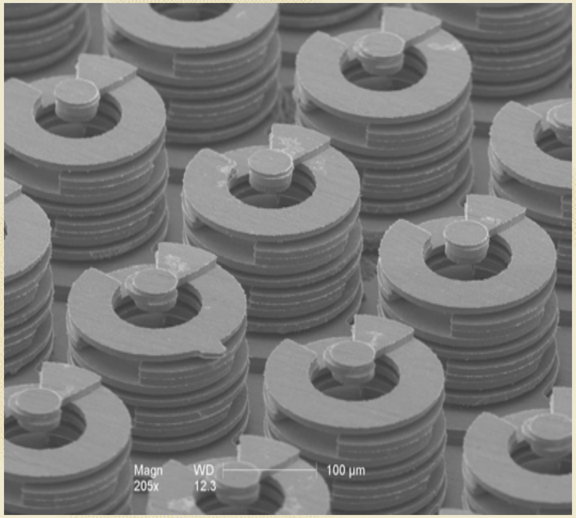
Vertical Micro-Probe Designs: Coil Spring

Design Variation	Probe pitch	Thickness of bending member	Spring outer diameter	Total Spring Height
Coil 1	100 μm	16 μm coil	80 μm	440 μm
Coil 2	100 μm	12 μm coil	80 μm	400 μm

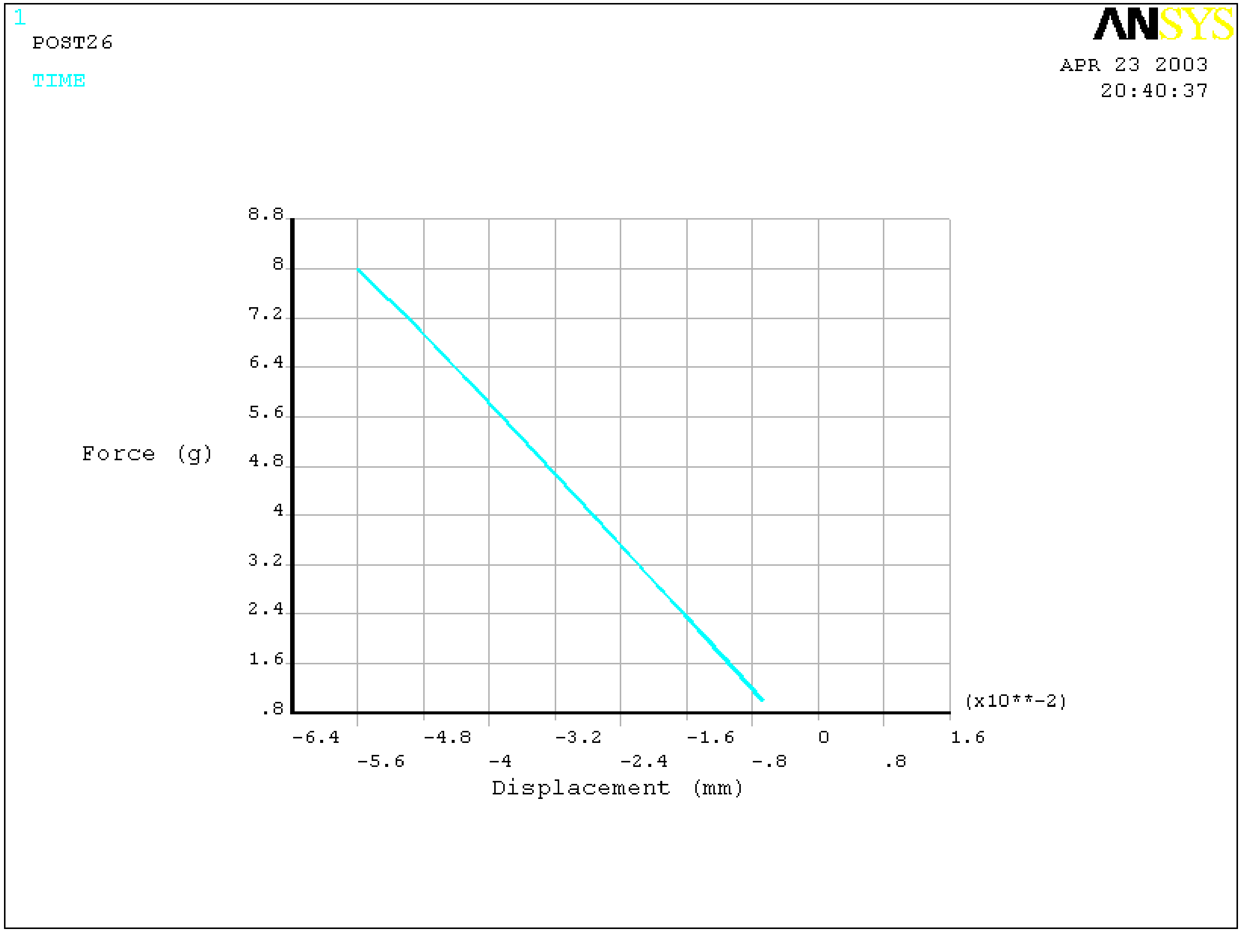
CAD model



Micro-probes



Mechanical Load-deflection Analysis: Coil Spring 1



F (g)	Deflection (um)
1.0000	6.77884
2.0000	13.5846
3.0000	20.4325
4.0000	27.3058
5.0000	34.2526
6.0000	41.2289
7.0000	48.4221
8.0000	55.9324

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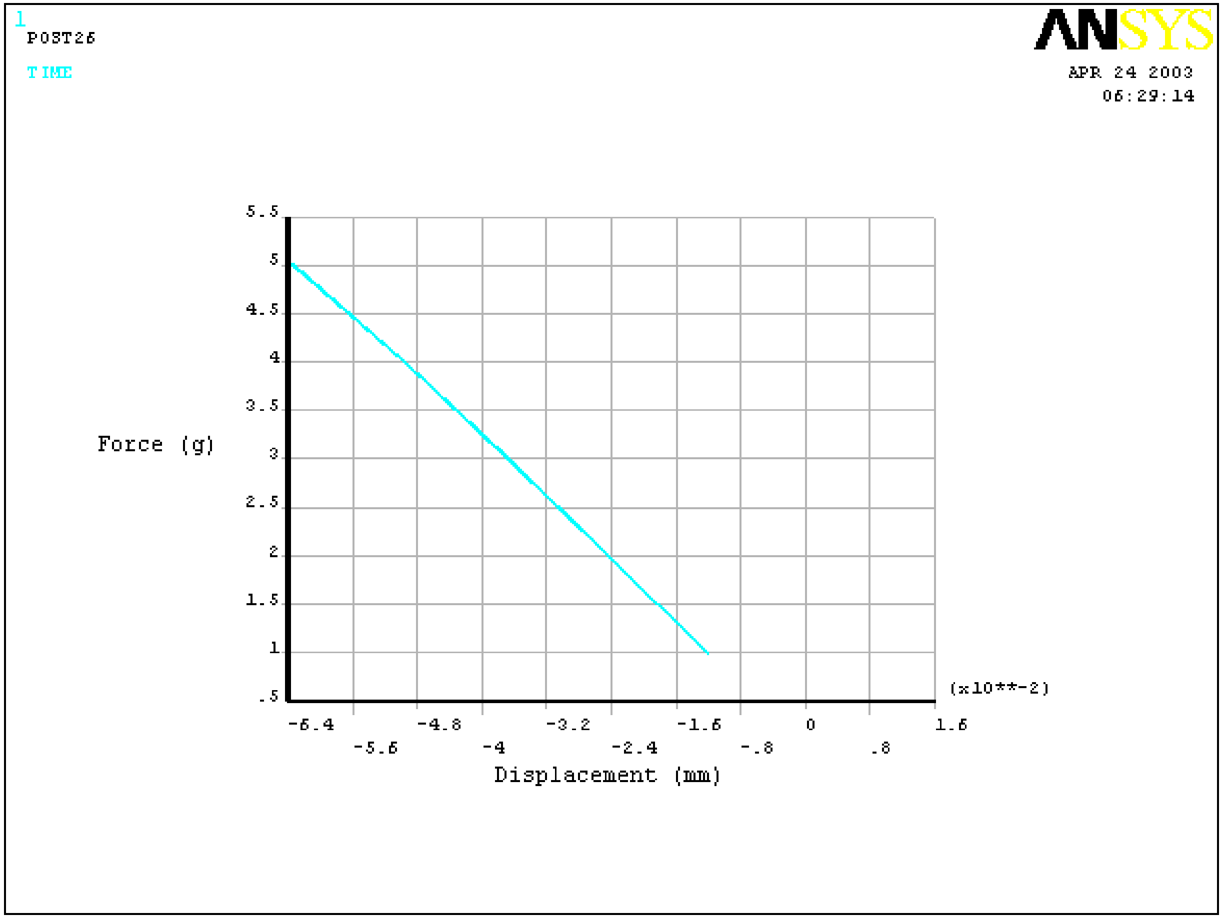
Mechanical Load-deflection Analysis: Coil Spring 2



F (g)	Deflection (um)
1.0000	12.1454
2.0000	24.4255
3.0000	36.7791
4.0000	49.5353
5.0000	63.3533

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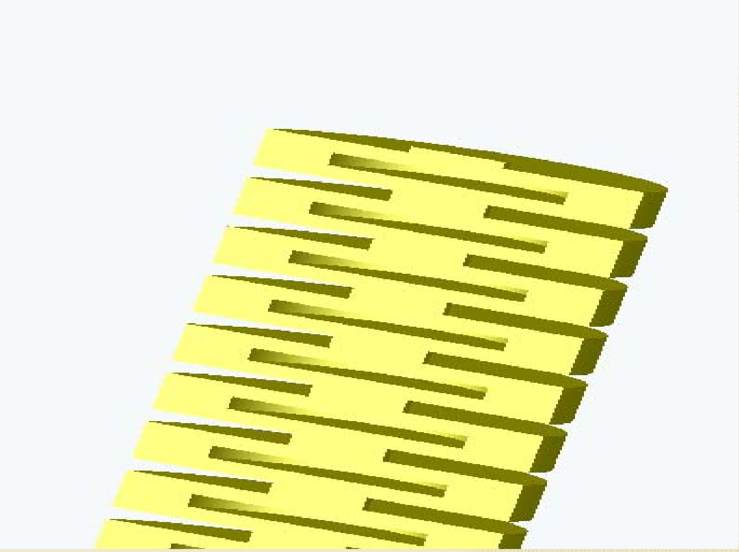
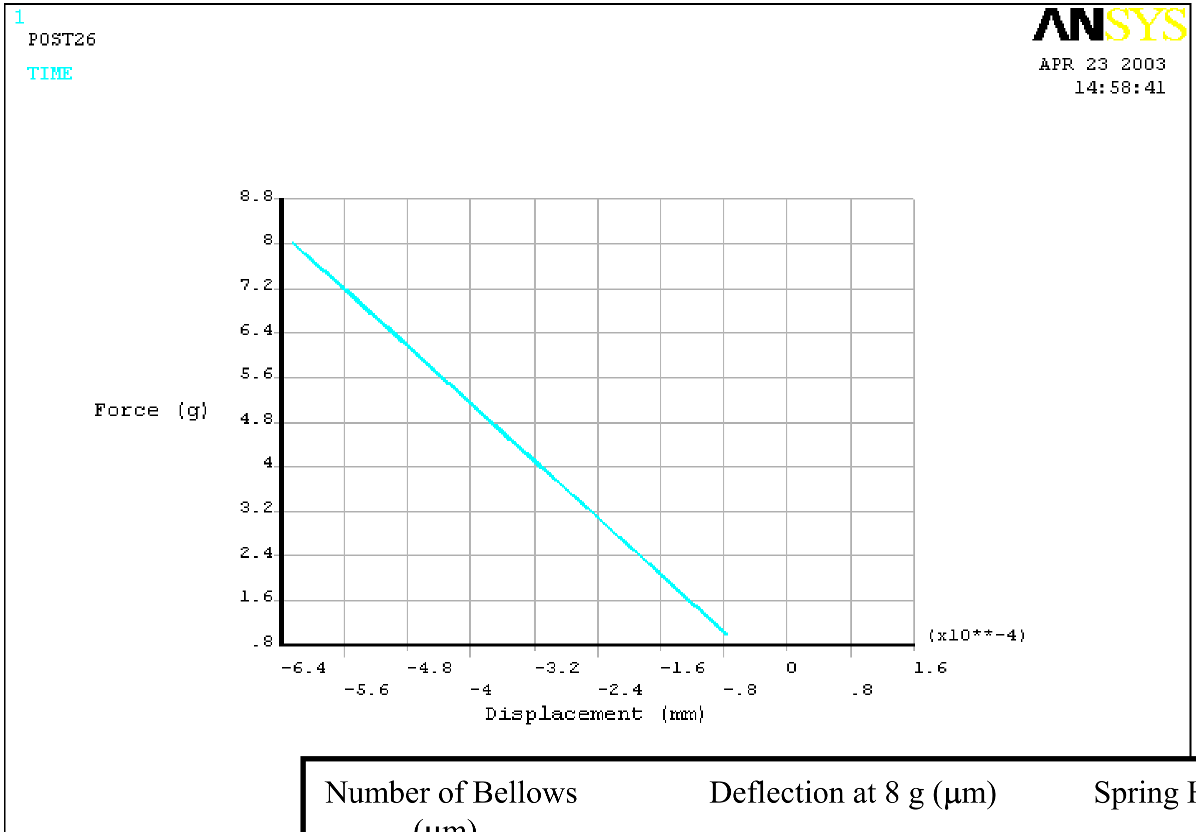
Vertical Micro-Probe Designs: Bellows

Design Variation	Probe pitch	Thickness of bending member	Spring outer diameter	Total Spring Height
Bellows 1	100 μm	4 μm plate	80 μm	variable
Bellows 2	100 μm	6 μm plate	90 μm	variable

CAD model



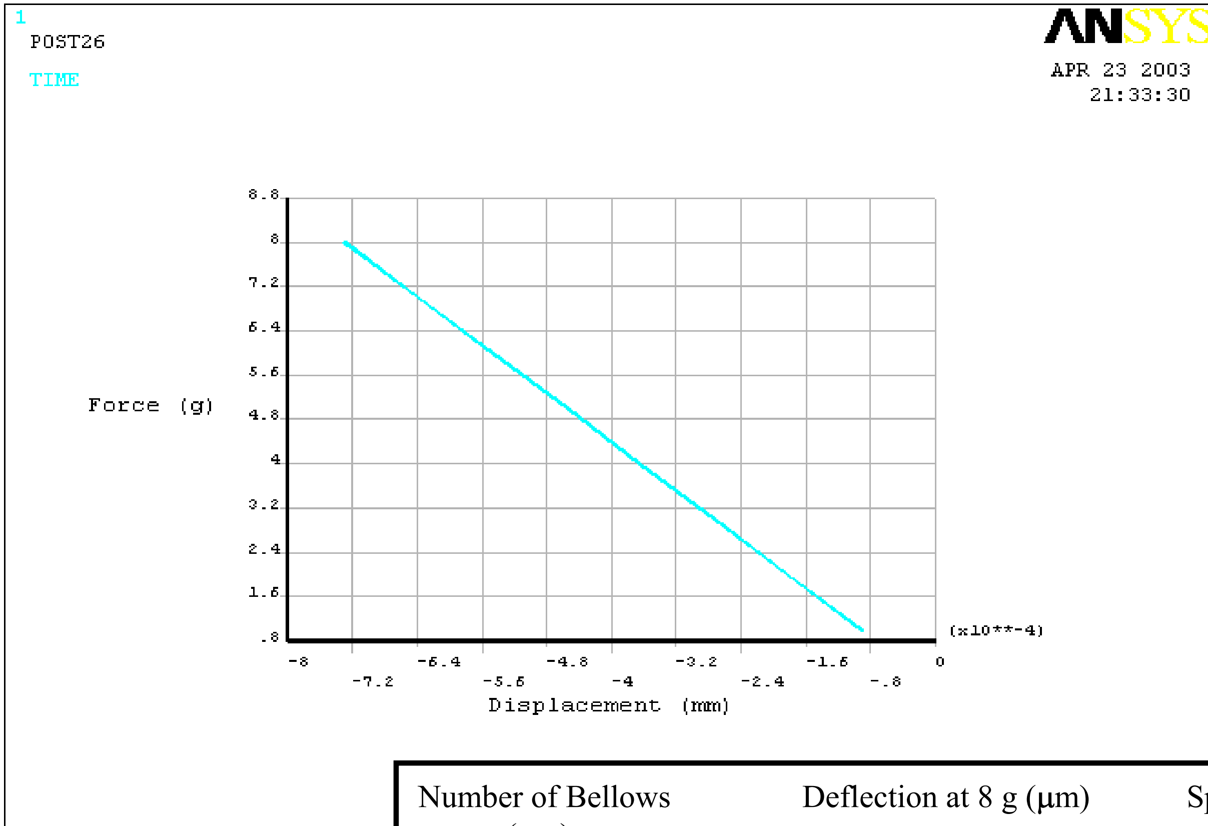
Mechanical Load-deflection Analysis: Bellows Design 1



F (g)	Deflection (um)
1.0000	0.0773939
2.0000	0.155016
3.0000	0.232827
4.0000	0.310819
5.0000	0.388983
6.0000	0.467311
7.0000	0.545795
8.0000	0.624427

Number of Bellows	Deflection at 8 g (µm)	Spring Height (µm)
1	0.624	16
10	6.24	160
50	31.2	800
100	62.4	1,600

Mechanical Load-deflection Analysis: Bellows Design 2



F (g)	Deflection (µm)
1.0000	0.0909079
2.0000	0.181920
3.0000	0.273029
4.0000	0.364228
5.0000	0.455511
6.0000	0.546872
7.0000	0.638304
8.0000	0.729801

Number of Bellows	Deflection at 8 g (µm)	Spring Height
(µm)		
1	0.730	20
10	7.30	200
50	36.5	1,000
100	73.0	2,000

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Vertical Micro-Probe DC Current Carrying Capacity Analysis

- Cross sectional area of most envisioned probe bodies will probably be 5-40 μm x 5-40 μm
- Current densities as low as 2 mA/μm^2 for 250 mA
- Local heating or "super temperature" at the point of contact
- 300 μm of assumed path length
- No heat sinks or convective effects
- Super temperature estimates based on literature
- Temperature increase of 36^{o}C and directly proportional to path length

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Conclusions

- Micro-fabrication process based on multi-layer electro-deposition of metals and capable of producing arbitrary 3-D shapes to improve device functionality and performance
- Initial design concepts investigate and validated through FEA simulations indicating feasibility of load-deflection behavior and DC current carrying capacity
- Initial designs fabricated and awaiting characterization
- Future work:
    - Characterize coil spring devices
    - Fabricate and characterize bellows design
    - Explore new designs