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Silicon Microcombs for Precision X-ray Foil Assembly

Yanxia Sun, Olivier Mongrard, Carl Chen, Ralf Heilmann, Craig Forest, Jenny You, Matthew Spenko, Mark L. Schattenburg

Space Nanotechnology Laboratory
MIT Center for Space Research

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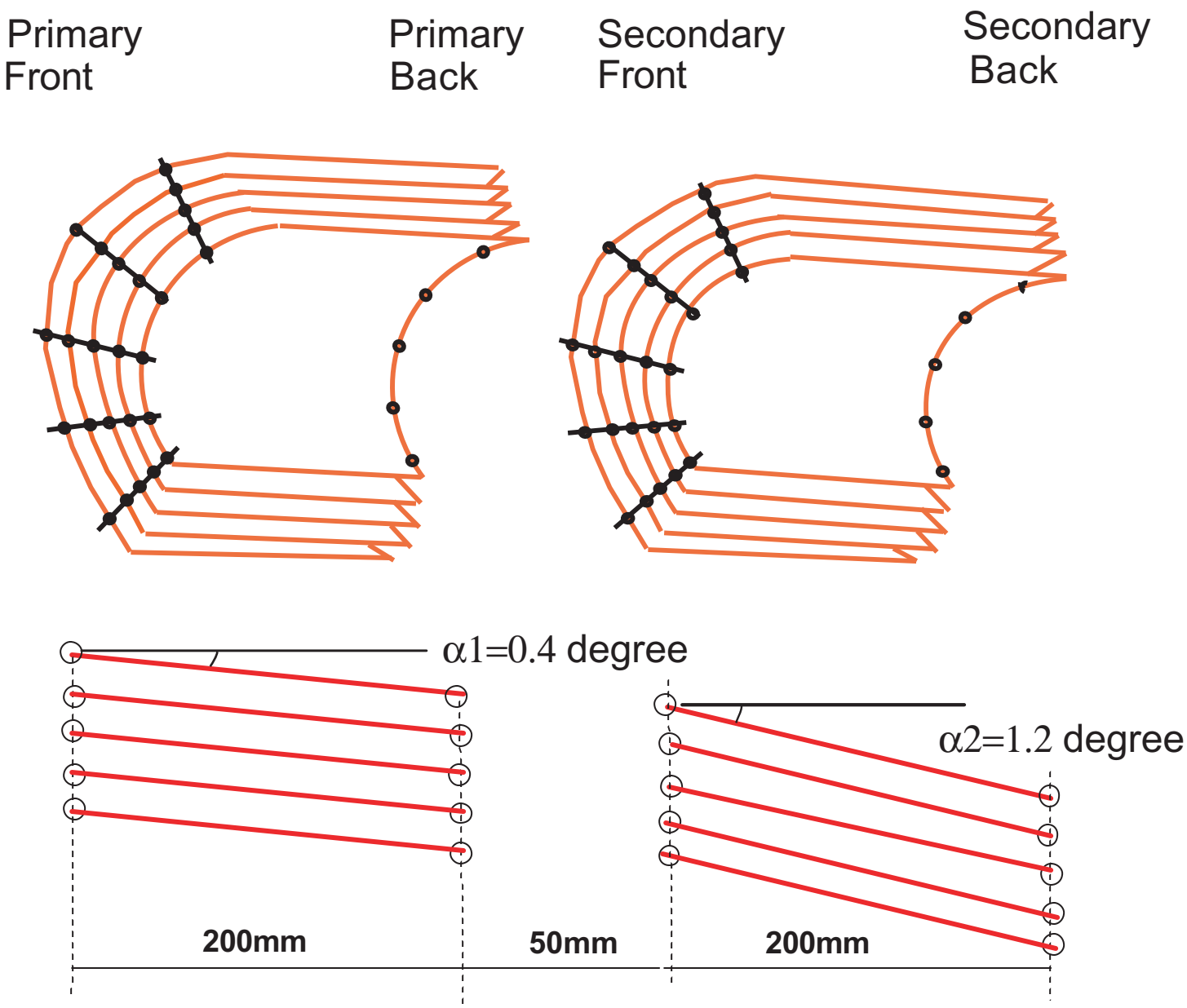
Space Nanotechnology Laboratory

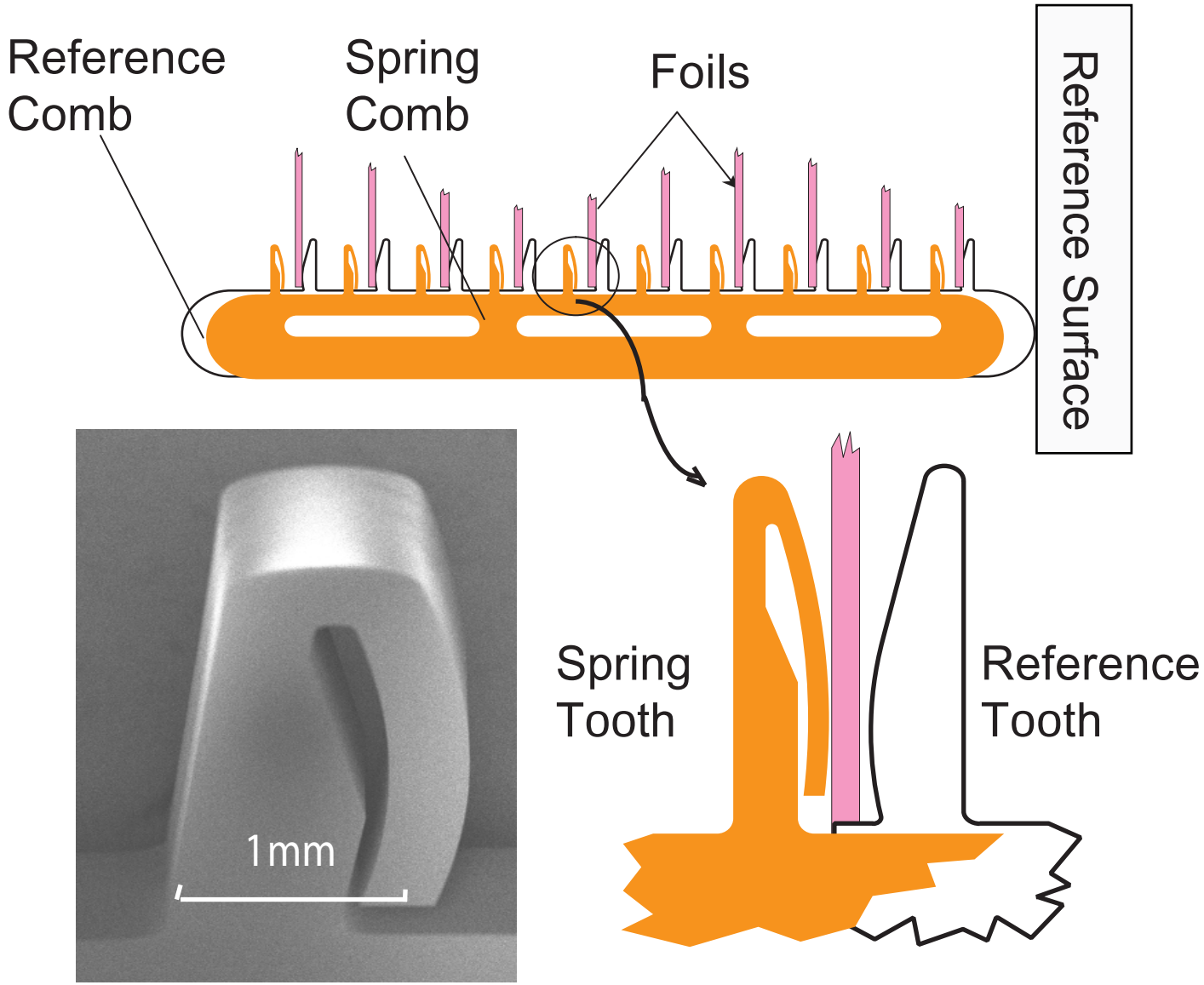
Outline

- Assembly Strategy for AEU Test #1
- Microcomb Design
  - Spring Comb Teeth
  - Reference Comb Teeth
  - Contact Point Control for Tilted Foil
  - Redesign Reference Comb for Abbe Error
- Microcomb Fabrication
  - Patterned on 150 mm Wafer
  - Achived 0.5 μm Accuracy (1" for 200mm Mirror Length)
- Timeline

Assembly Requirement for AEU Test #1 X-ray Foil

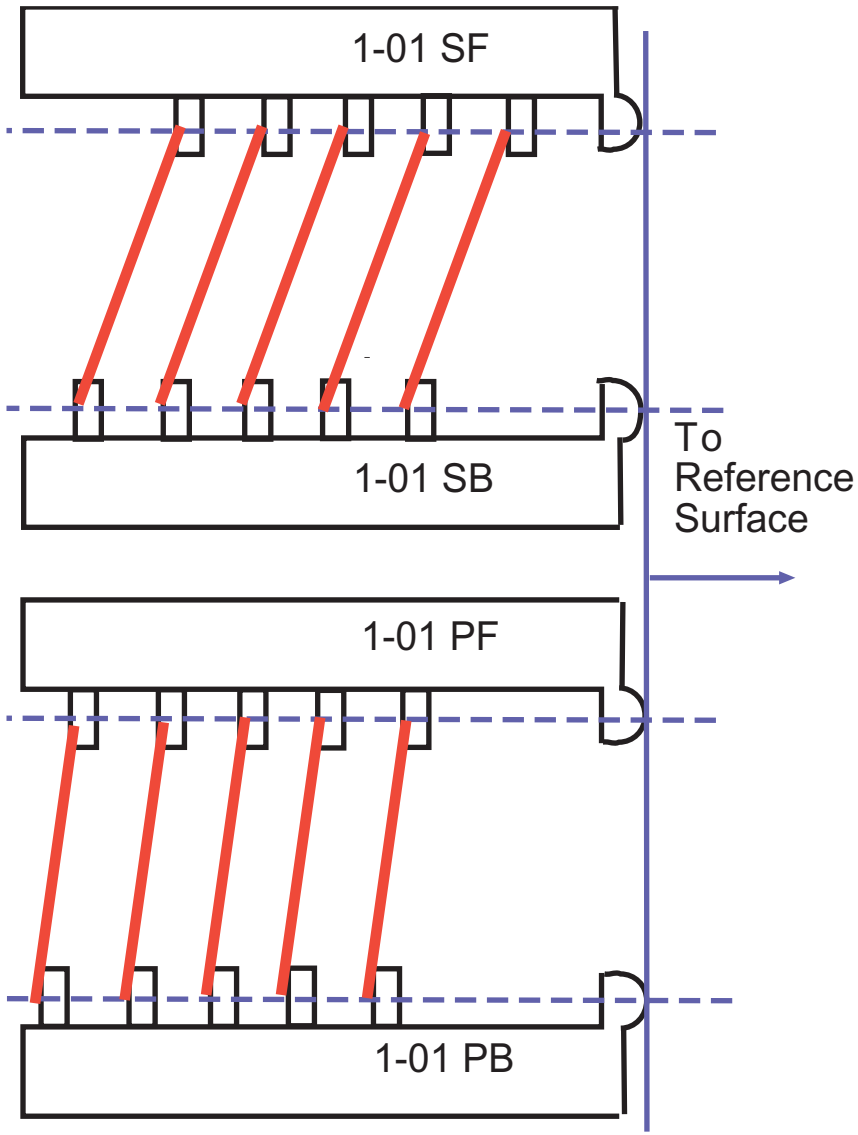


MIT Solution: Silicon Microcomb



Scanning Electron Microscope Images for microcomb teeth

Design Functional Requirement for Microcomb



Previous

--Apply a certain force to push foil in place
--Accommodate foil thickness variation
--Accuracy requirement for reference

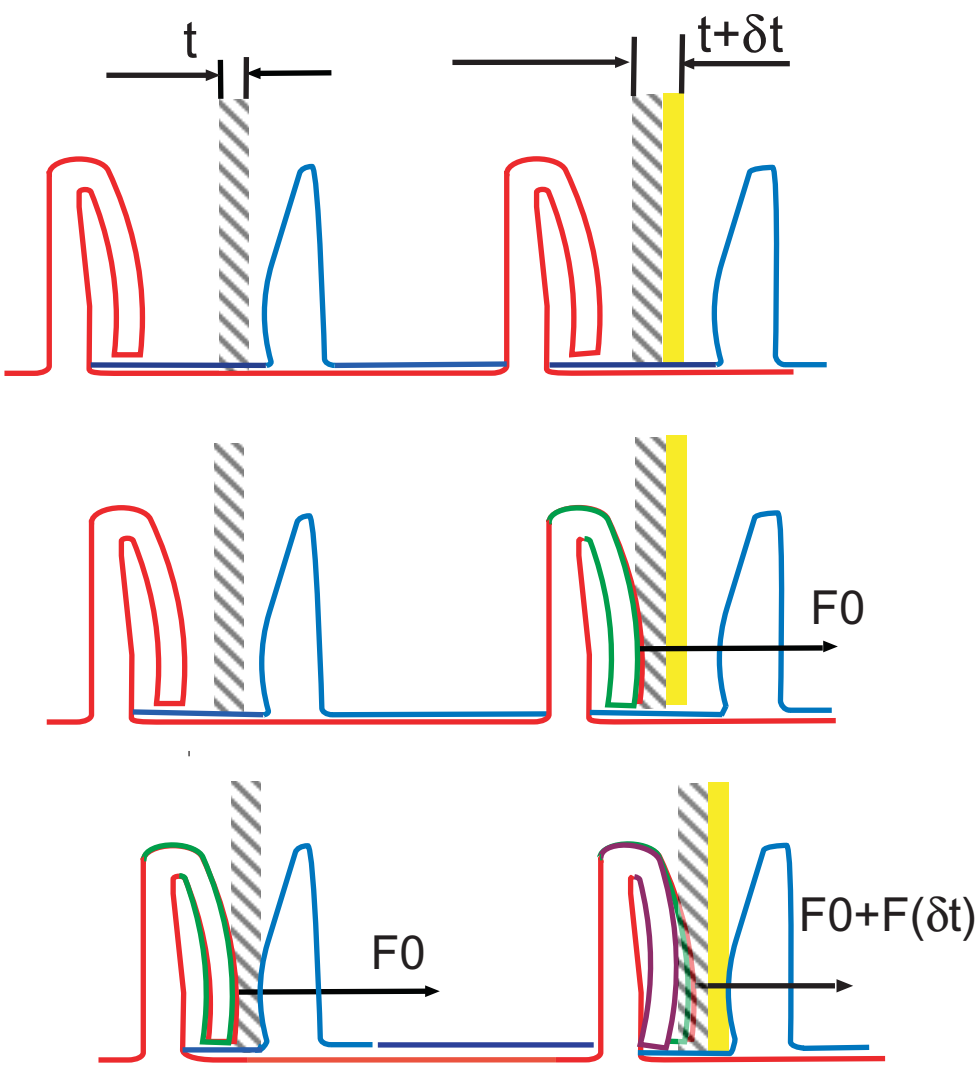
New

--To allow small tilted angles for foils
--To avoid Abbe error for assembly
--To avoid torque for each single foil

Future

--Improve reference accuracy

Microcomb Teeth Design

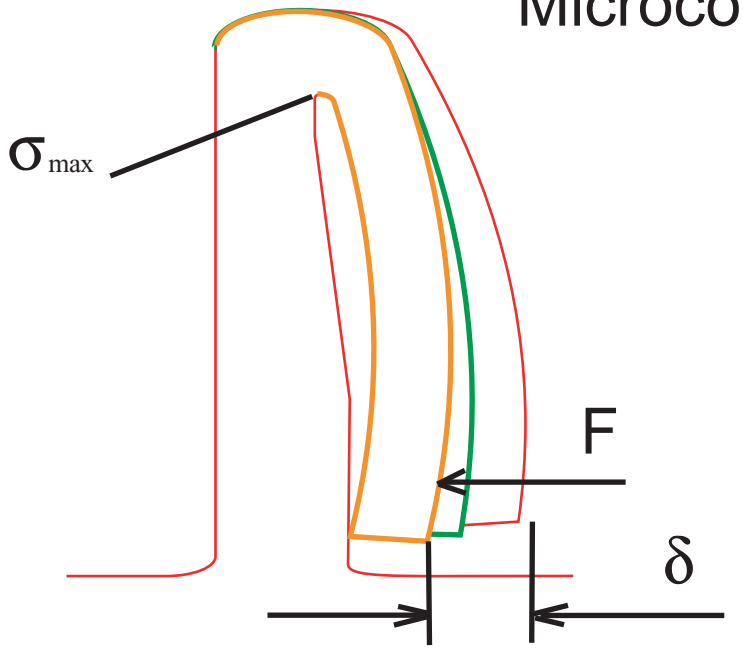


Foil Thickness: t
Foil Thickness Variation: δt

To Push the Foils:
- Preload Force: F0
- Preload Tip Deformation: δ0

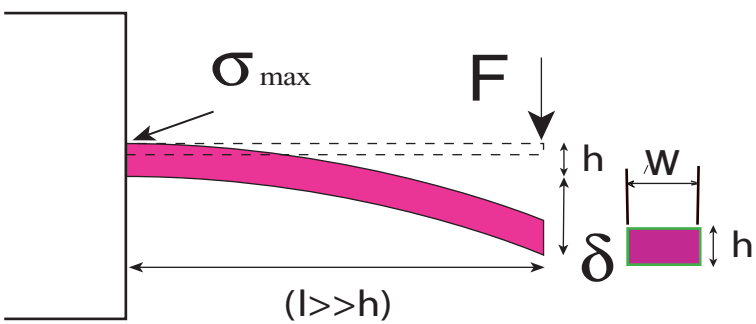
To Hold the Thicker Foil in Place:
- Extra Tip Deformation: δt
- Extra Force: F(δt)

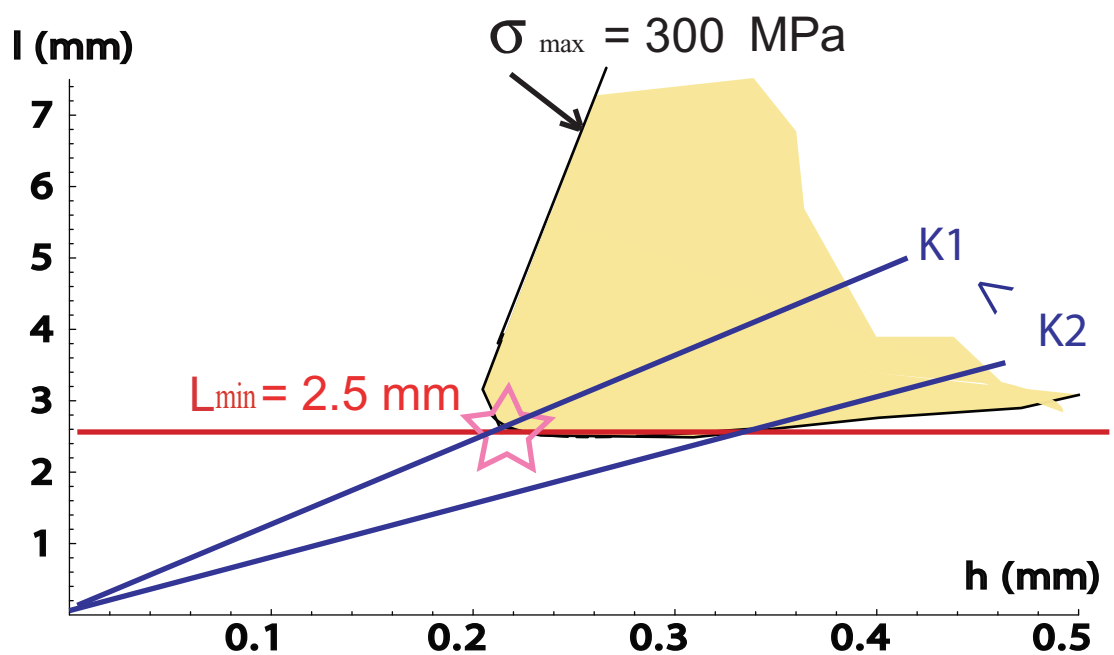
Microcomb Design for Spring Teeth



Preload Force: F0 > 0.18 N
Extra Deformation: $\delta t > 20\ \mu m$
Max Stress: $\sigma_{max} < 300$ MPa

Keep the teeth shorter;
Minimize the contact force (stiffness).

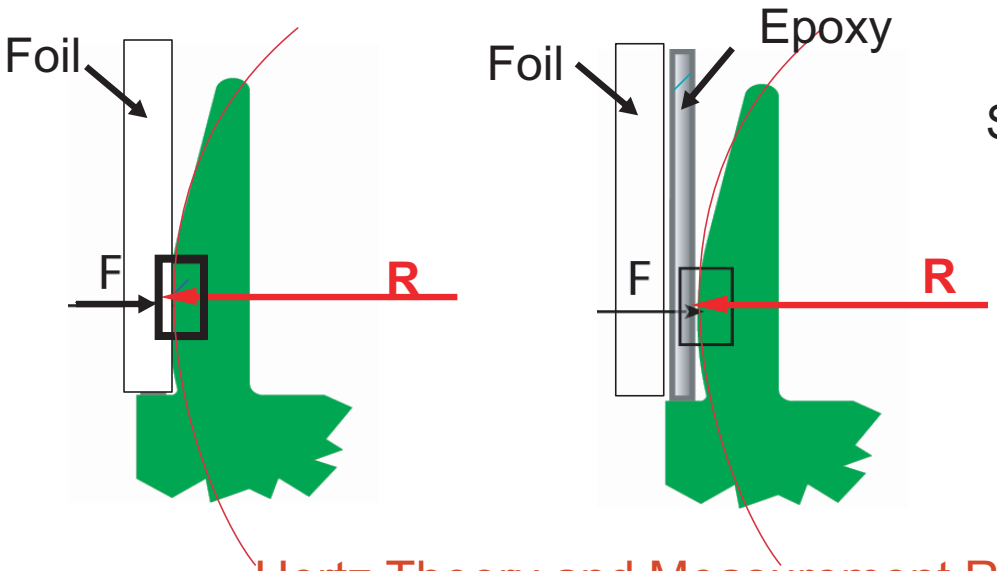




Maximum stress: $\sigma_{max} = \frac{3E}{2}\frac{h}{l^2}\delta$

Stiffness: $K = \frac{F}{\delta} = \frac{Ew}{4}\left(\frac{h}{l}\right)^3$

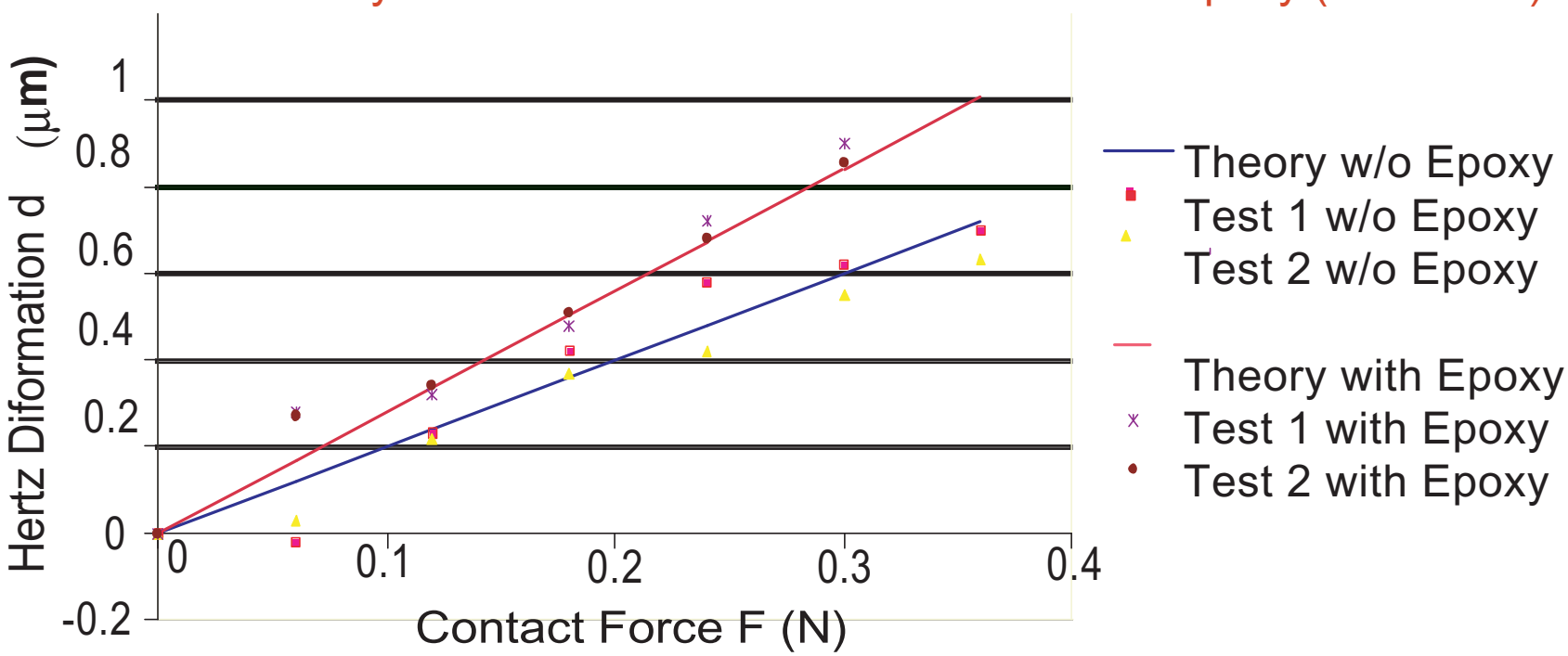
Microcomb Design for Reference Teeth



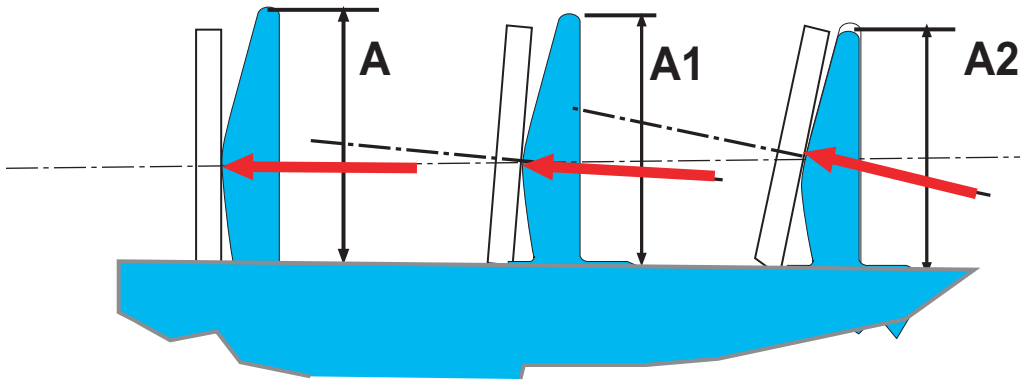
Surface Distortion Due to Hertz Contact Force

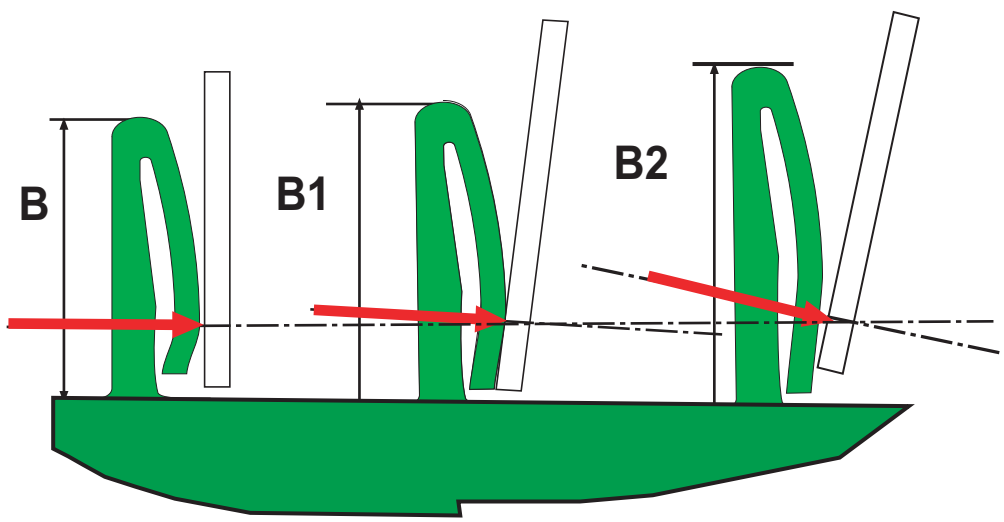
Surface Deformation: d
Contact Force: F
Comb Arc Radius: R

Hertz Theory and Measurement Results with & w/o Epoxy (R=7.5mm)



Microcomb Design for Tilted Foils





Tilted angle	Length of Reference Teeth A (mm)	Length of Spring Teeth B (mm)
$\alpha\ 0 = 0$	5.8200	5.8000
$\alpha\ 1 = 0.4^{o}$	5.7676	5.9061
$\alpha\ 2 = 1.2^{o}$	5.6629	6.1183

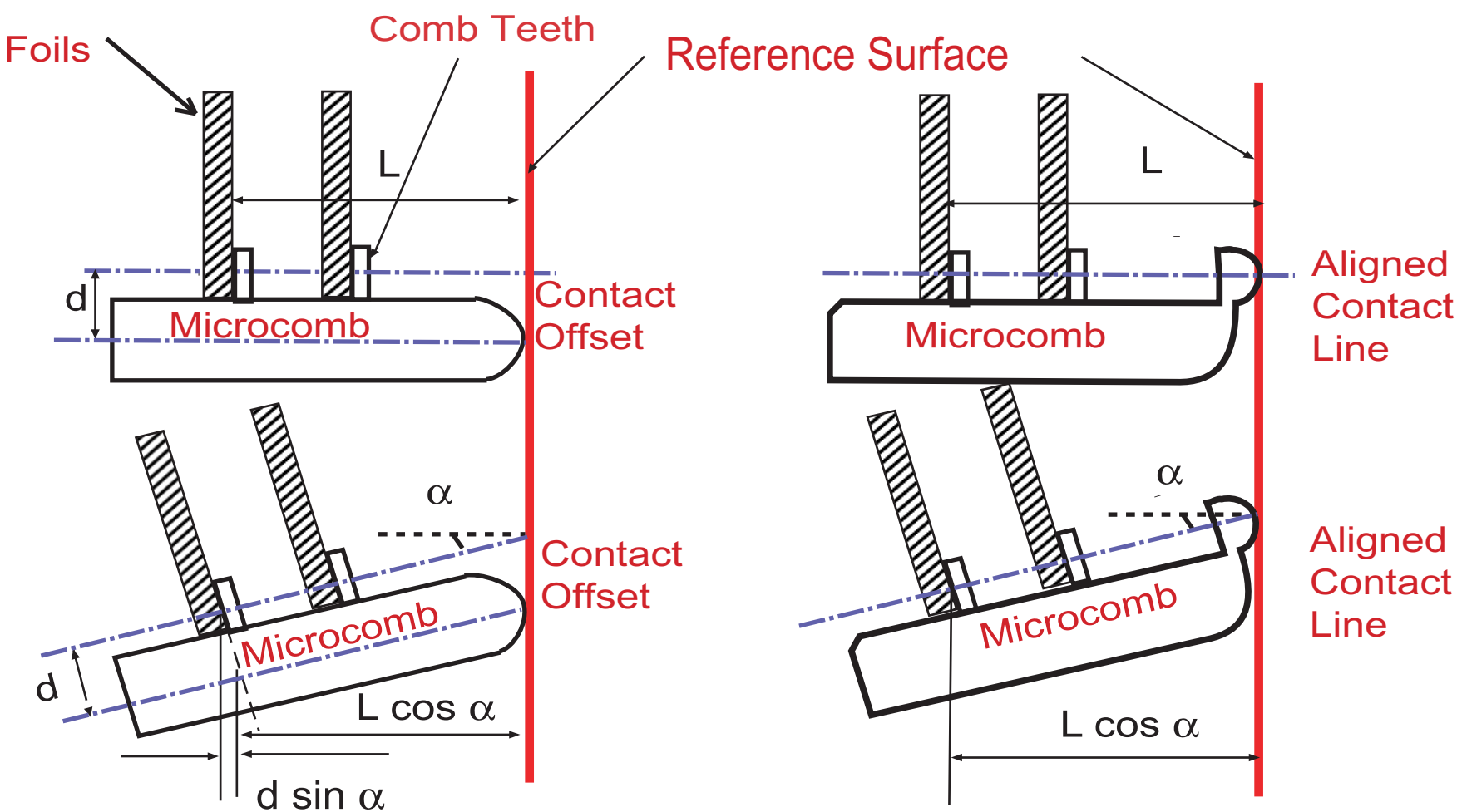
Microcomb Design for Abbe Error

Pitch Error:

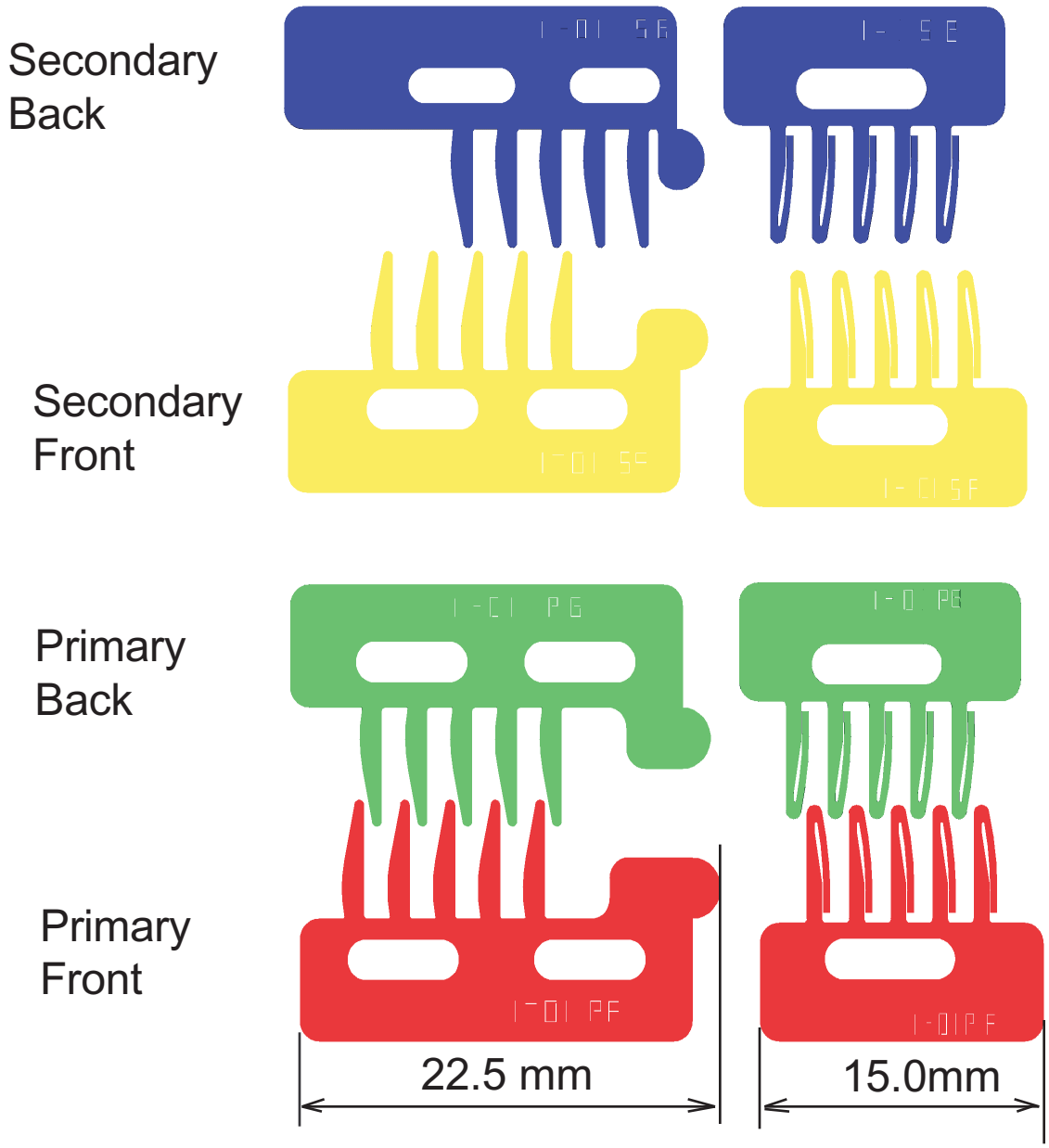
$$|d \sin \alpha + L (\cos \alpha - 1)|$$

Pitch Error:

$$|L (\cos \alpha - 1)|$$

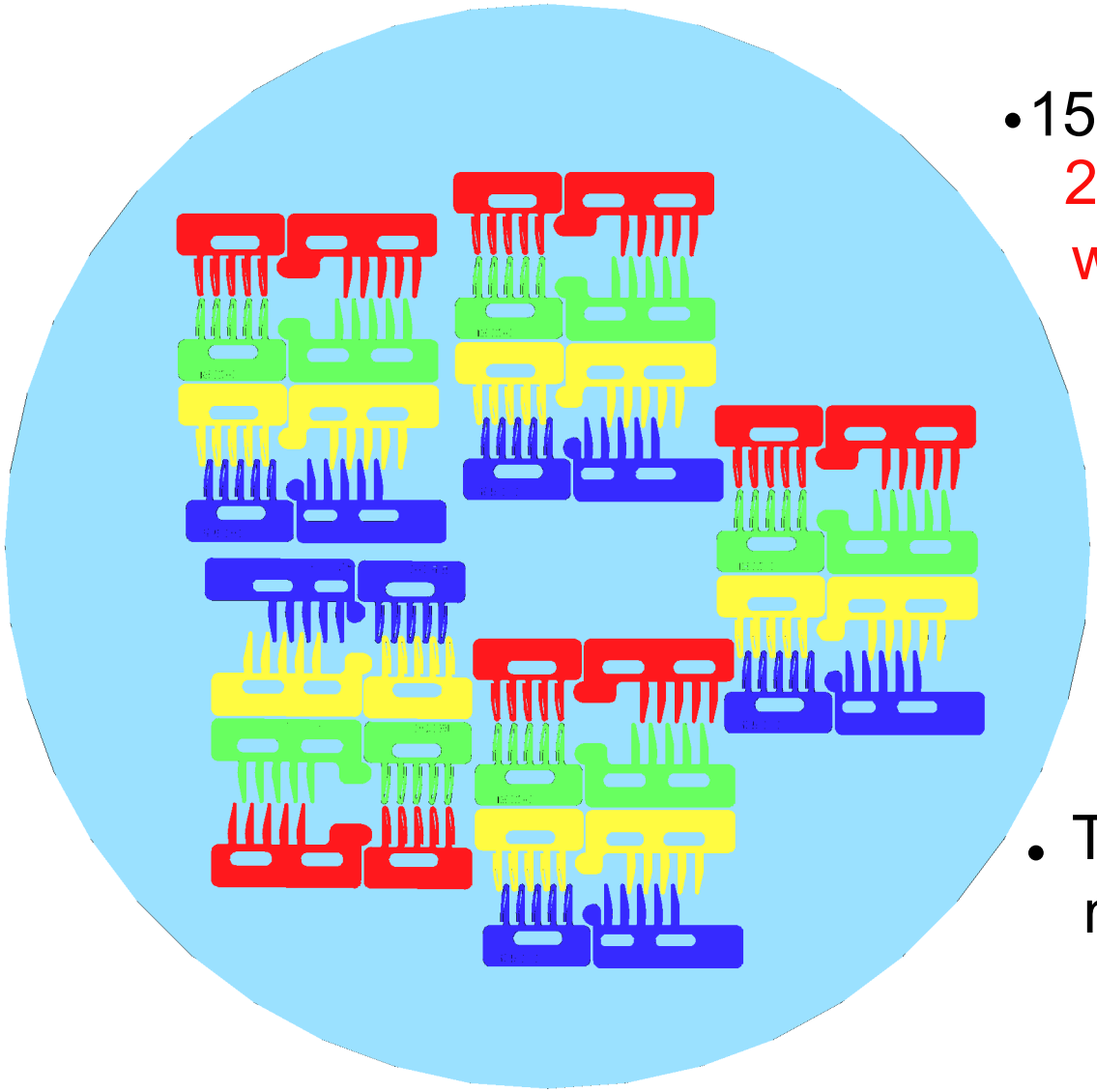


Microcomb Design Summary



- Four positions for microcombs;
- Five sets of combs required per position;
- Five teeth required per comb.

Microcomb Fabrication



- 150mm wafer, 400 μm thick; 20 sets of combs within one wafer
- E- beam lithography for mask generation; 0.1 μm accuracy
- TMDRIE fabrication for microcomb; 0.5 μm accuracy

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Timeline for AEU Test #1 Microcombs

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Oct. 14	Oct. 21	Oct. 28	Nov 4	Nov 11	Nov. 18	Nov .25	Dec .2	Dec. 9, 2001	Dec. 15	Dec. 23	Dec.30	Jan.6	Jan. 13, 2002	Jan.20	Jan.27	Feb.3	Feb. 12, 2002
Conceptual design																		
ProE CAD Drawing																		
Mask Drawing																		
Mask Fabrication																		
Daughter Mask Fabrication																		
Comb Fabrication Practice																		
Comb Fabrication																		