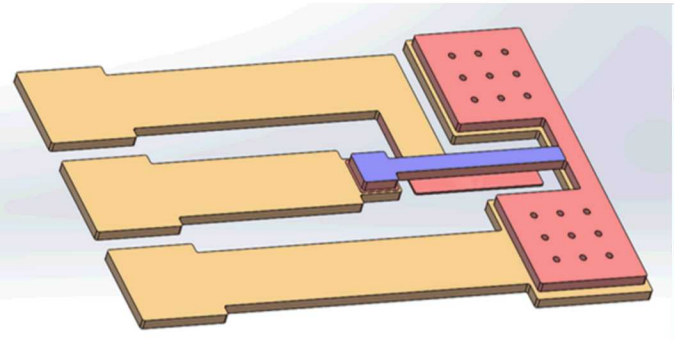
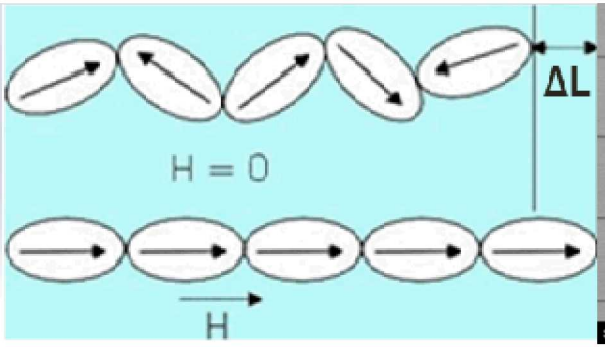
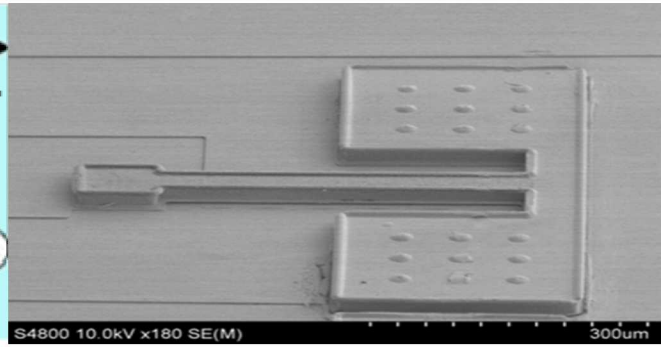
SAND2016-9789C







Modeling and Characterization of Electroformed MEMS Variable Capacitors for Cobalt Iron Magnetostriction Measurements

Eric D. Langlois, Patrick S. Finnegan, Mark H. Balance, Jamin R. Pillars, Todd Monson, Andrew E. Hollowell, Christian L. Arrington, Charles J. Pearce and Christopher R. St John

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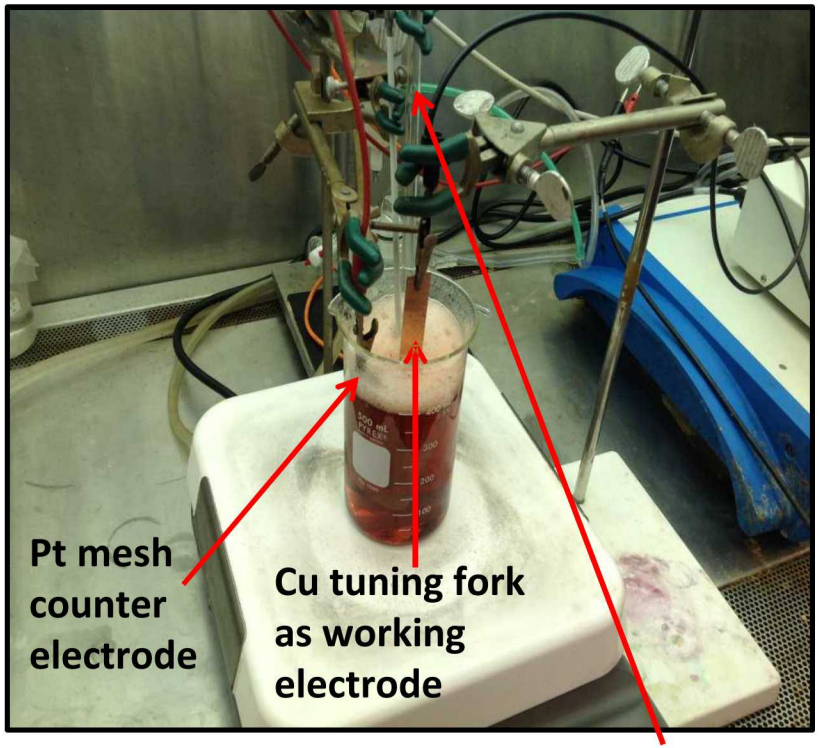
New Method to Electrodeposit CoFe

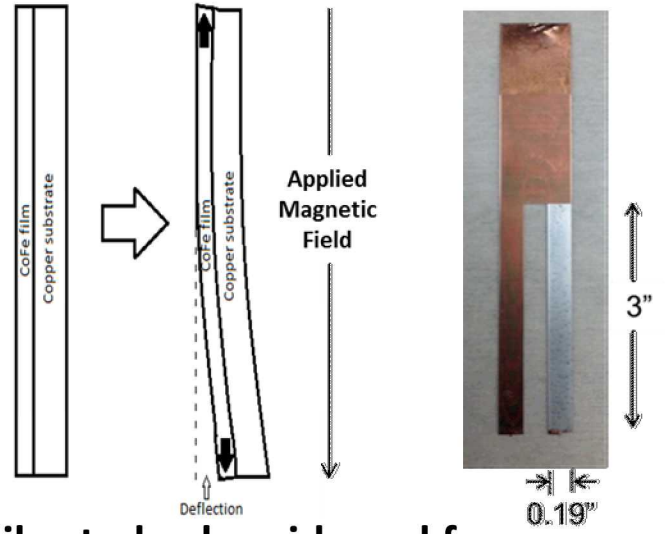
Previous work:

- Hunter, D., et al., *Giant magnetostriction in annealed $Co_{1-x}Fe_x$ thin-films.* Nat Commun, 2011. 2: p. 518.

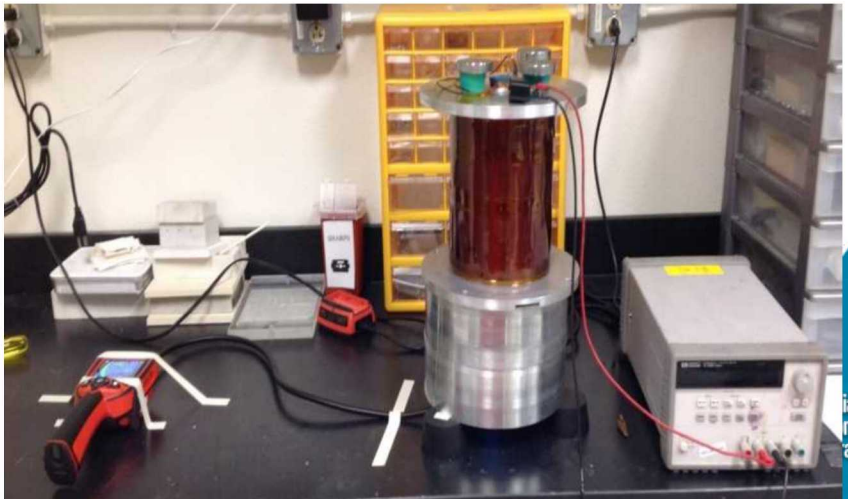


Expression du Tremolet de Lacheisserie and Peuzin:

$$\lambda_{eff}(D_{sat}) = \frac{2(D_{\parallel} - D_{\perp})E_s {t_s}^2 (1+\upsilon_f)}{9E_f L^2 t_f (1+\upsilon_s)}$$



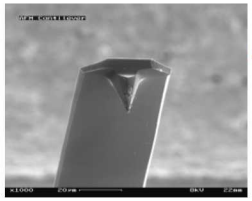
Calibrated solenoid used fo[illegible]



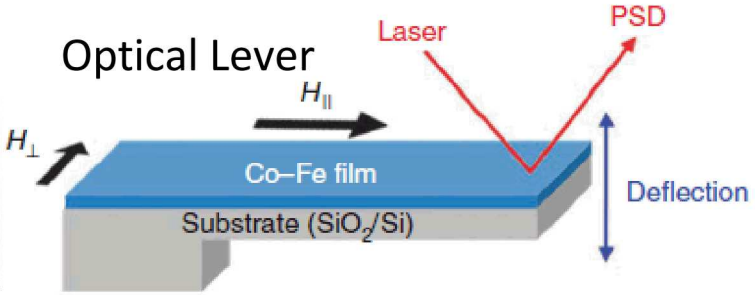
Our work:

Jamin Pillars, Eric Langlois, Christian Arrington, Todd Monson, "Electrodeposition Processes for Magnetostrictive Resonators," U.S. Patent Application #14876652, October, 2015.

Motivation – Existing Measurement Techiques Infeasible



Optical Lever

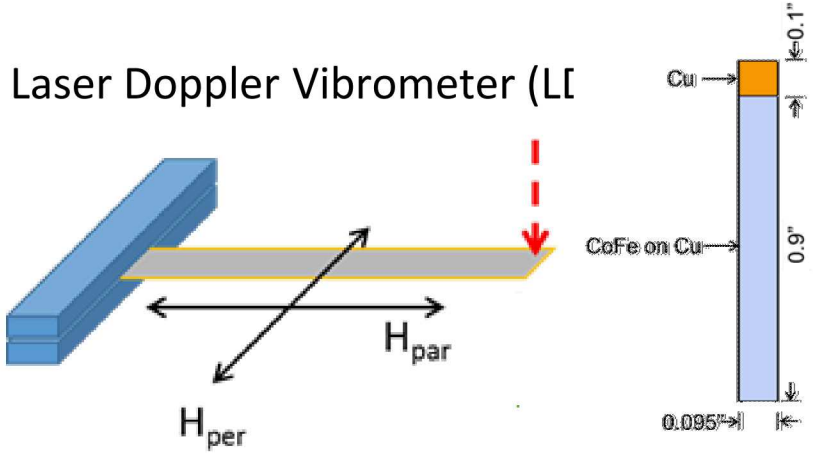


- Strain resolution (nε)
- Incompatible with electrodeposition
- Dedicated AFM with Helmholtz coils

Hunter, D., et al., Giant magnetostriction in annealed Co1−xFex thin-films. Nat Commun, 2011. 2: p. 518.

- Strain resolution (pε)
- Compatible with electrodeposition
- Cost prohibitive (>$150k)
- Torsional effects

Laser Doppler Vibrometer (LD

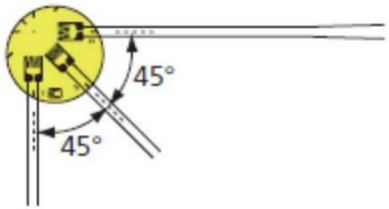


Staruch, M., NRL, communications

Triaxial, 0°/90°/45°

Resistance: 120 Ω

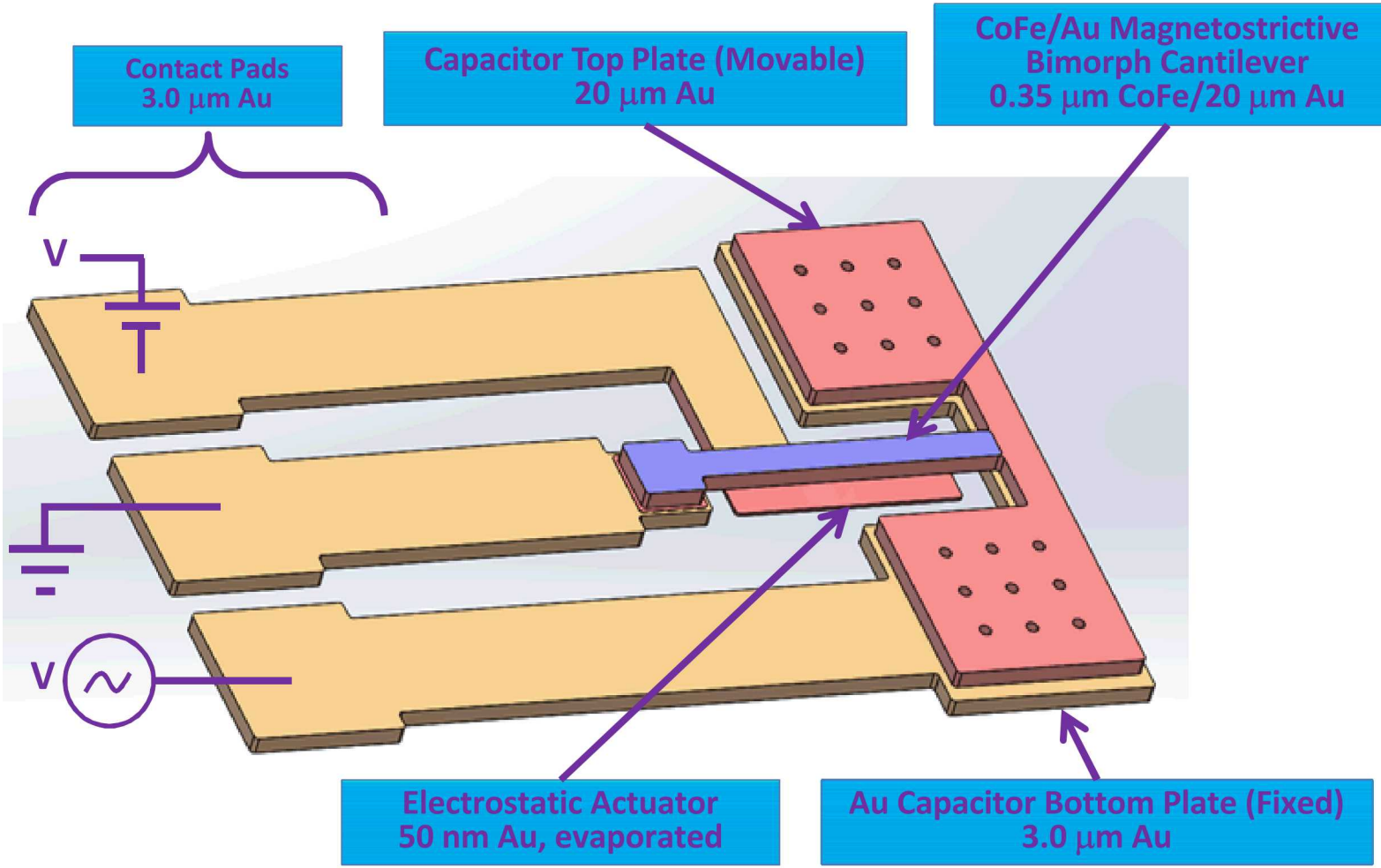
Gage factor: Approx. 2.1



- Medium strain sensitivity (± 5με)
- Not good for thin films
- Film adhesion poor

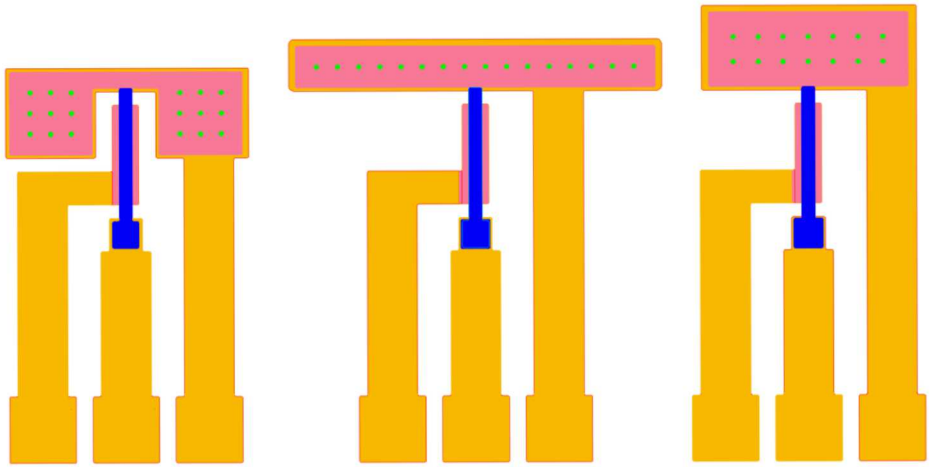
Resistive Strain Gauge

Variable MEMS Capacitive Displacement Sensor



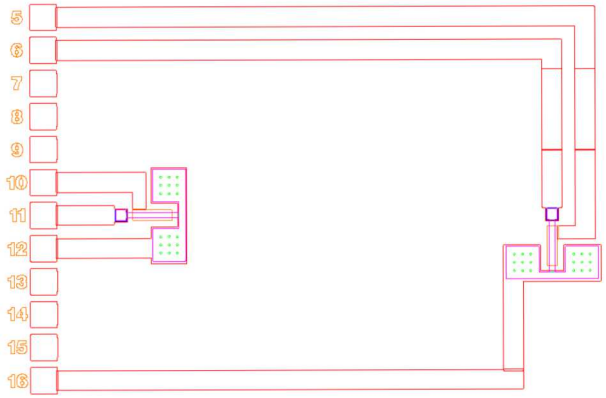
**Model courtesy of Adam Thorpe, Sandia National Laboratories*

Designs

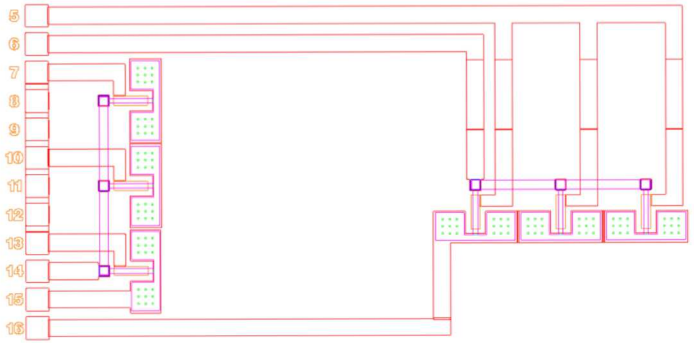


MEMS Cap 1 MEMS Cap 2 MEMS Cap 3

- Capacitor areas the same, 0.135 mm^2
- Parallel plate capacitance = 1.26 pF



Single orthogonal pair



Triple orthogonal pair

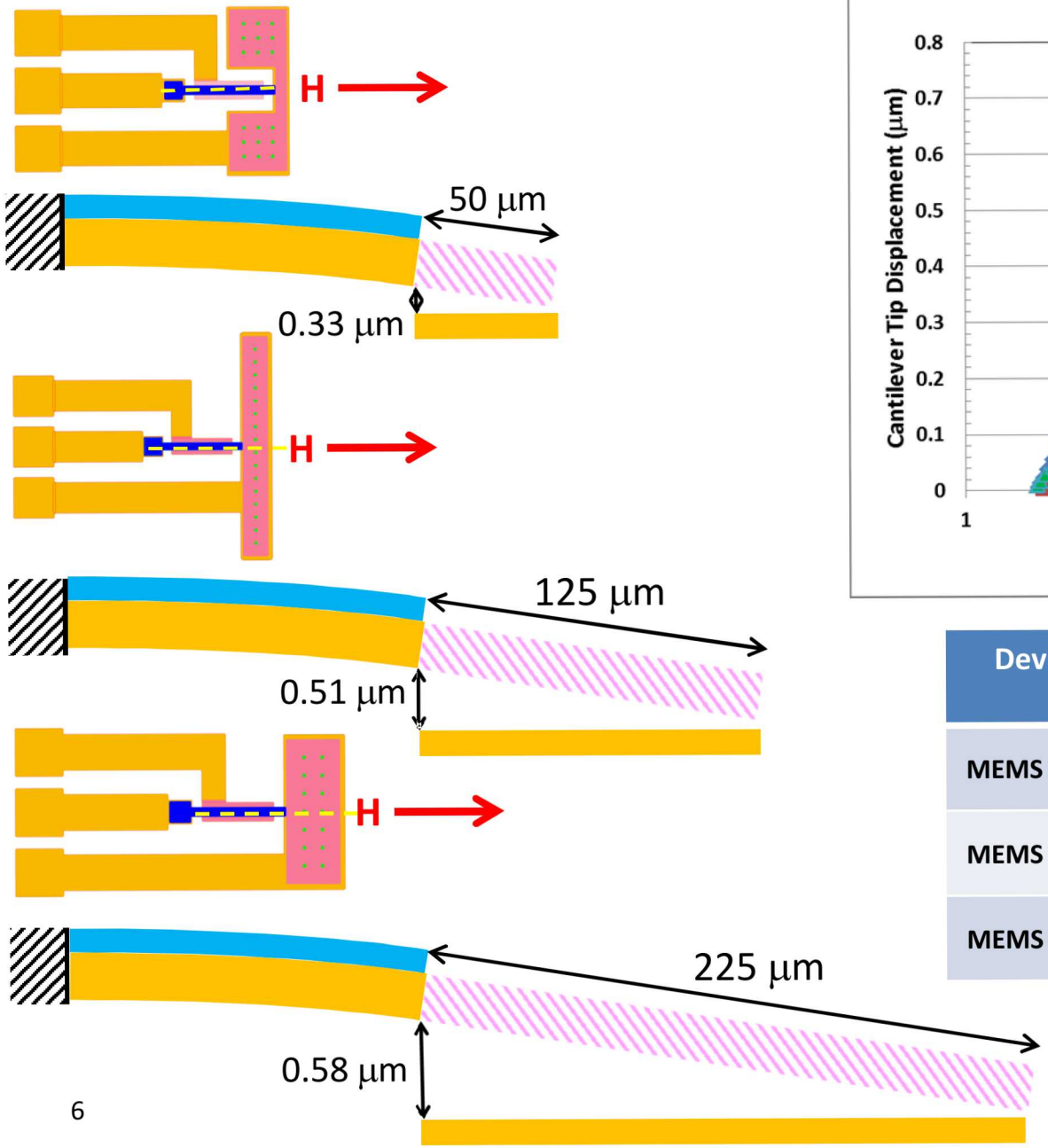
Advantages

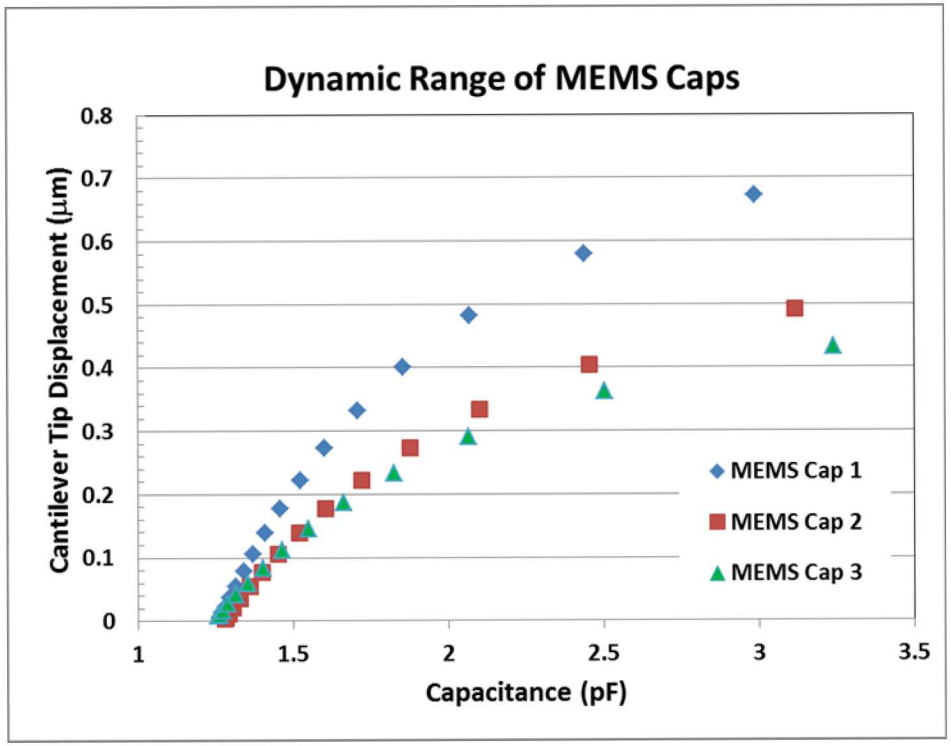
- **Chip-scale** (5mm (W) X 10mm (L))
- **Orthogonal** (patterned by photolithography)
- **Parallel sensors possible** (boosts signal)
- **Less prone to torsional effects** (improves accuracy)
- **Reduced instrumentation complexity**

Disadvantages

- **Complex fabrication** (Sandia is good at this!)

Dynamic Range



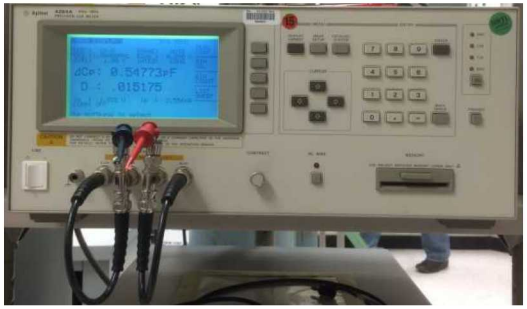


Device	Dynamic Range	Sensitivity (μm/pF)
MEMS Cap 1	1.7 pF 0 to 0.67 μm	0.39
MEMS Cap 2	1.8 pF 0 to 0.49 μm	0.27
MEMS Cap 3	2.0 pF 0 to 0.42 μm	0.21

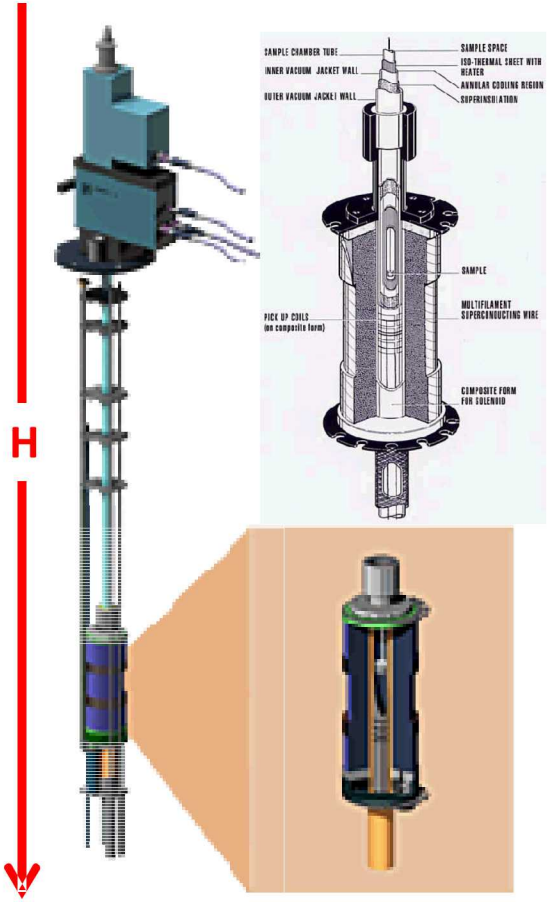
λ = 0 to 80 με ($\pm$ 1 με)

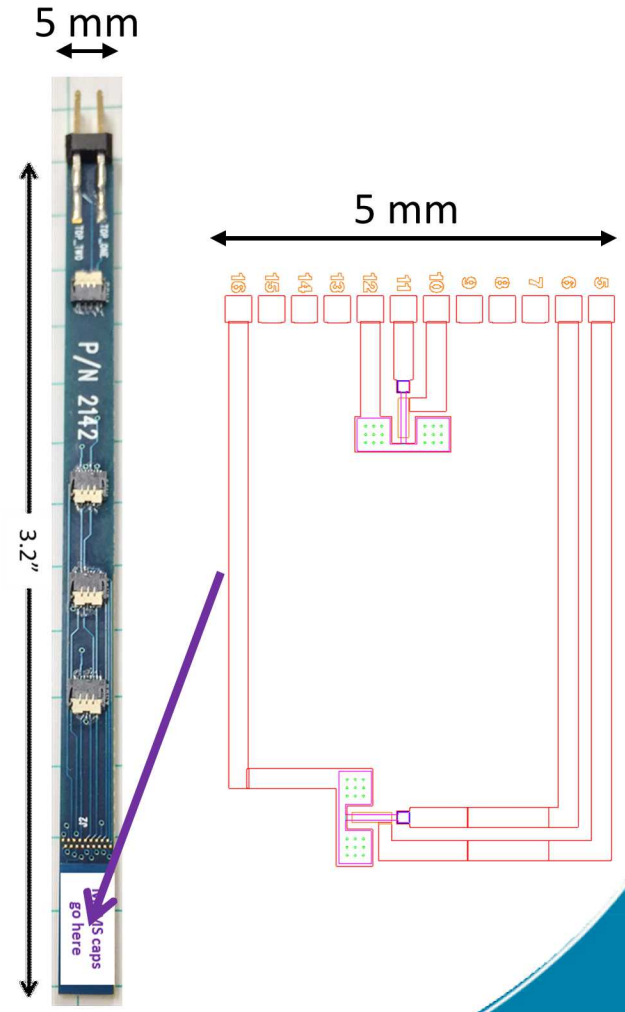
(MPMS-7) superconducting quantum interference device (SQUID) magnetometer.

Agilent 4284A 20hz-1MHz Precision LCR Meter



Quantum Design Magnetic Property Measurement System (MPMS) probe assembly





Custom PCB

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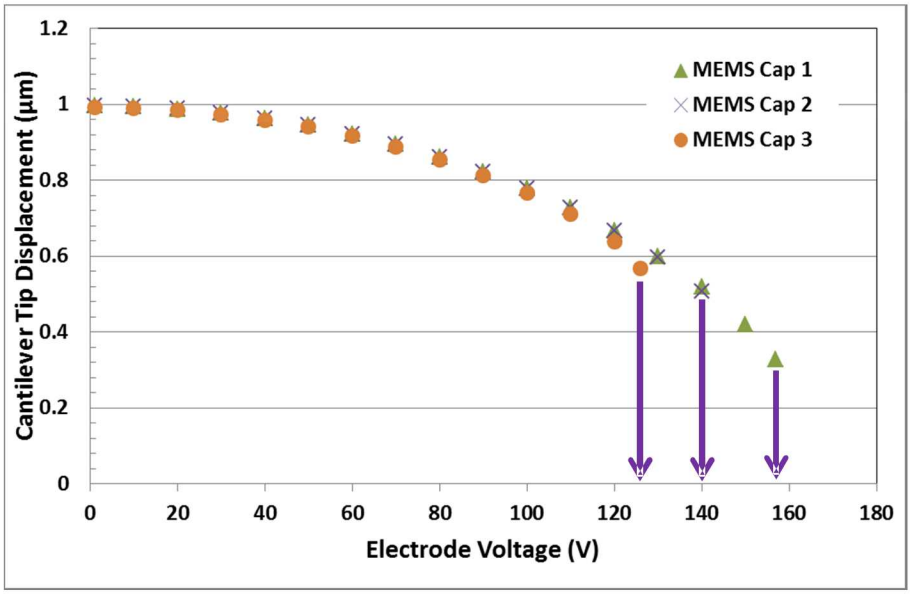
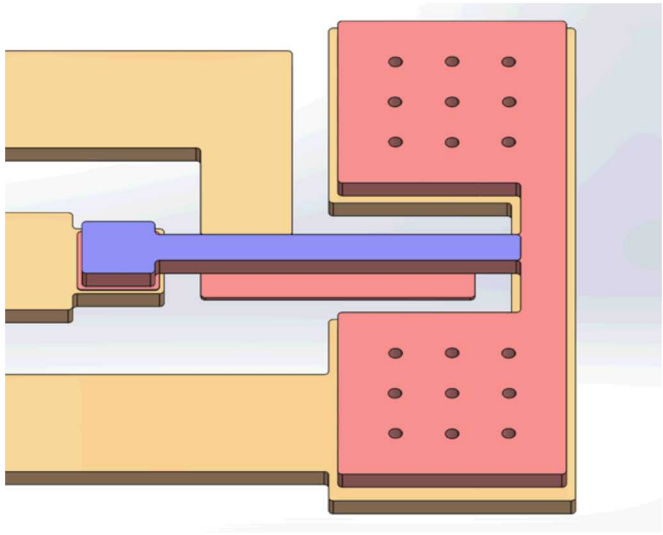
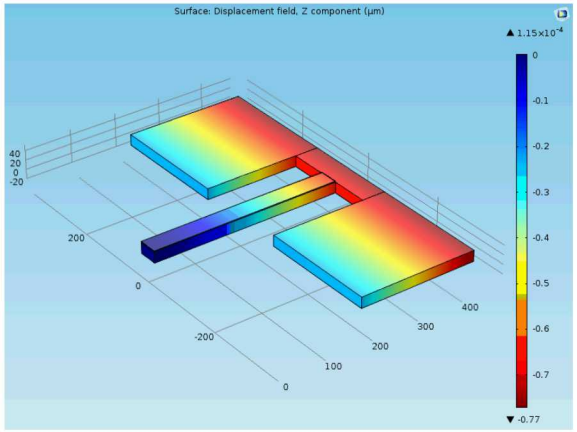
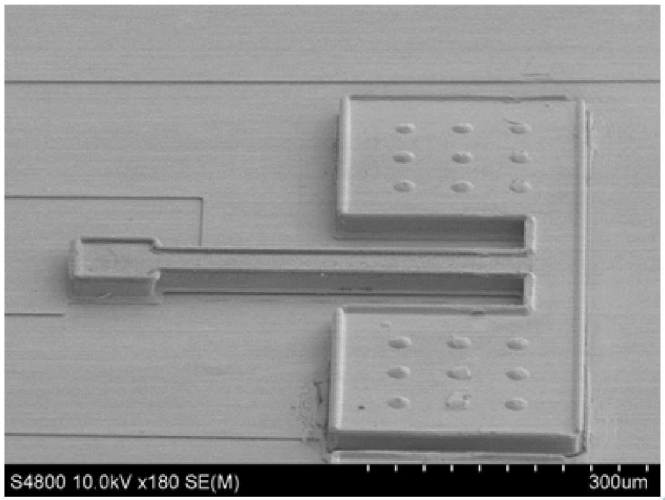
Variable MEMS Capacitors







3D surface displacement plot



1st pass MEMS variable capacitor test structures

Sandia National Laboratories

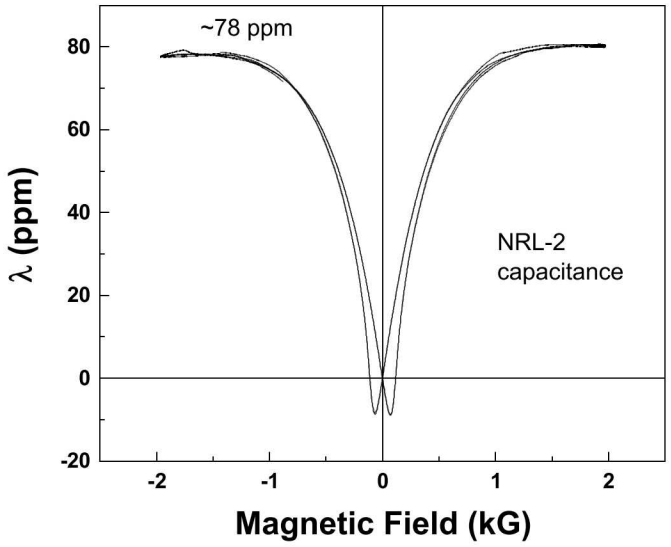
Conclusions

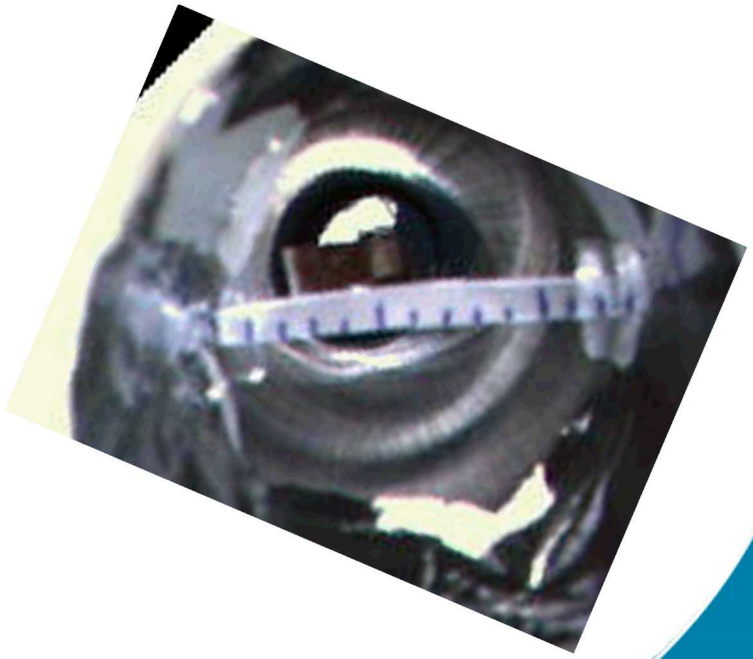
- New method for measuring magnetostriction in electroplated CoFeB films needed.
- MEMS variable capacitors conceived for this purpose.
- 3 different MEMS variable capacitor architectures were designed and modeled using AutoCAD and COMSOL FEM.
- Dynamic ranges varied from 0 to 0.67 μm over 1.7 to 2.0 pF depending on capacitor architecture.
- Magnetostriction values of λ = 0 to 80 $\mu\varepsilon$ ($\pm$ 1 $\mu\varepsilon$) were modeled.
- 1st pass capacitors built but more development is needed.

Thank You!

Acknowledgements:

- Individuals for their support and contributions to the vision of this work: Dianna Blair, (Project Manager), Keith Ortiz, Wahid Hermina.
- Metglas Inc. for providing free samples of magnetostrictive alloy ribbon used for calibration of our magnetic test equipment.
- This project was supported by Laboratory Directed Research and Development (LDRD) Project Number 150356.





Independent verification of magnetostriction in Sandia bimorph CoFe/Copper cantilevers confirmed by Margo Staruch, Ph.D., Naval Research Labs (NRL).

CoFe	Chemicals	H_3BO_3	$Co(H_2SO_3)_2$	TMAB	Sorbitol	Na Saccharin salt	Ascorbic acid	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$
	Conc. (mol/L)	0.5	0.4	0.1	0.01	0.05	0.05	0.08
Au	Chemicals	Neutronex 309i Gold – 2.4 troy oz gold/gal, 40 ppm thallium						
	Conditions	700 Hz pulse			25% duty cycle			2 mA/cm2

*CoFe: Bath ph=2.0; Bath temperature=50°C

Au: : Bath ph=9.5; Bath temperature=50°C

For more details, please see "Optimized CoFeB Alloy Films for Electroformed Resonators" on Friday, 7 October 2016: 11:40, 305 A (Hawai'i Convention Center)