SAND2019-3162PE

Metal Micromachining Team

CAMD user's meeting April 25, 2015

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National Laboratories

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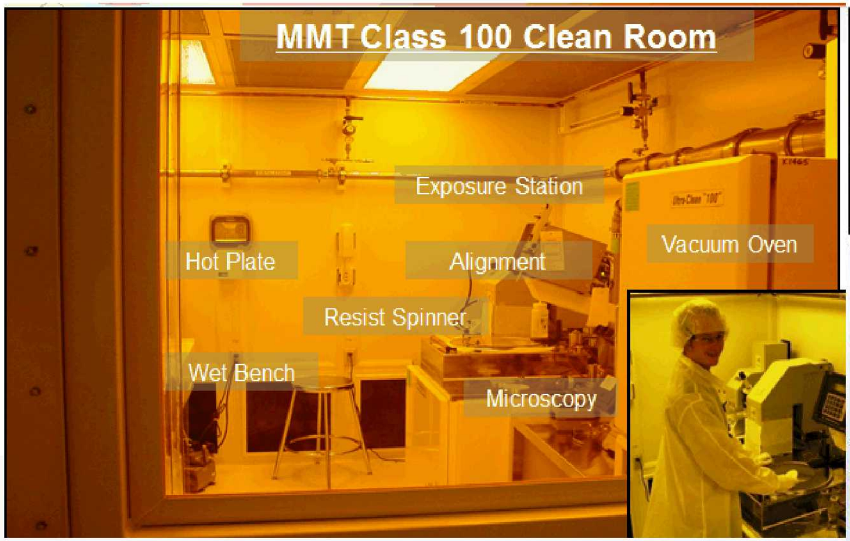
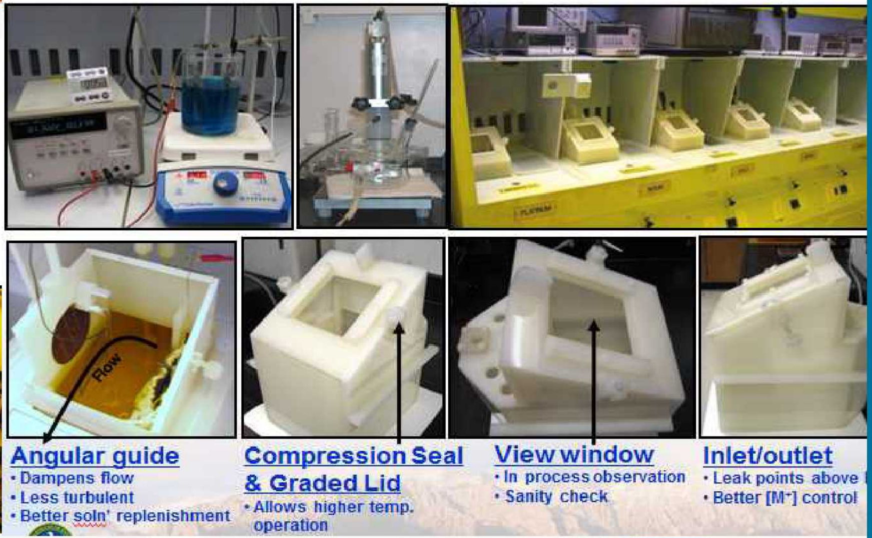
Lithography



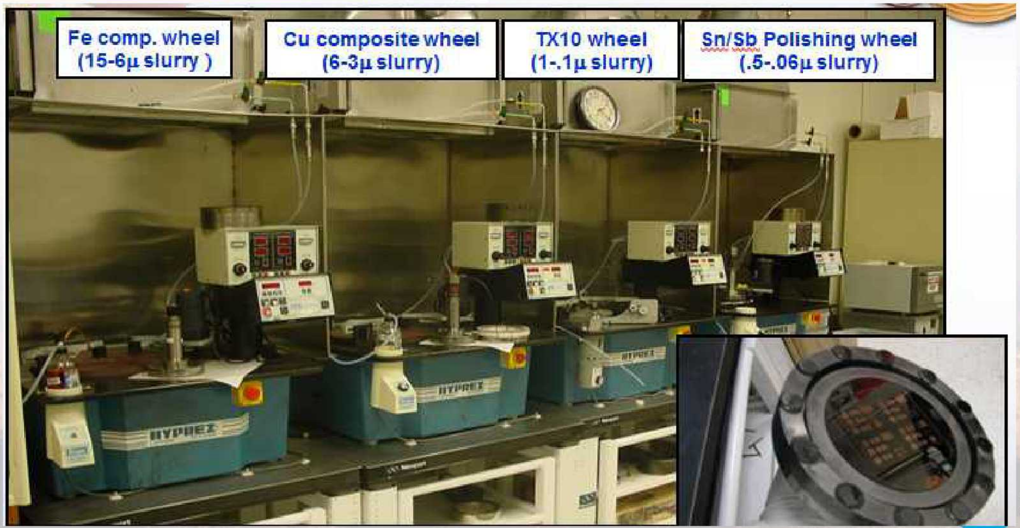
Electroplating



Chemistries

1. *Hard Gold*
2. *Soft Gold*
3. *Copper*
4. *Nickel*
5. *Indium*
6. *Platinum*
7. *Monel*
8. *Kovar*
9. *Permalloy*
10. *NiW*
11. *_BiTe*
12. *SbTe*
13. *PbTe*
14. *Te*
15. *PbS*
16. *PbSe*
17. *CoFe*

Chemical Mechanical Polishing (CMP)



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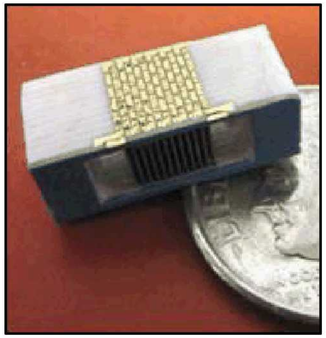
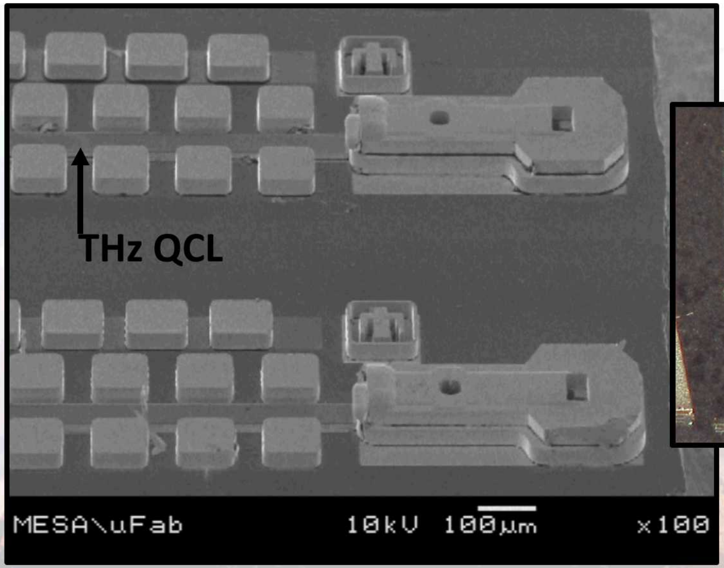
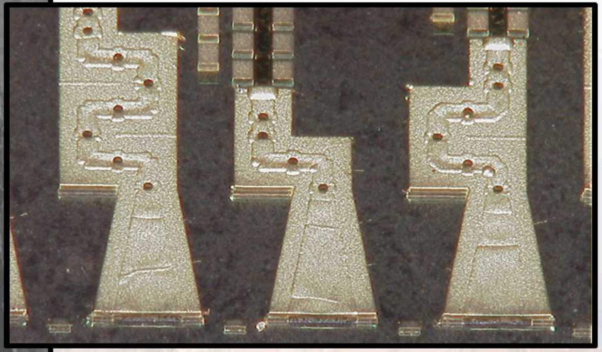
Plating Applications

Masking achieved through unique fixturing and controlled polymer deposition



3-D Integrated Gold THz Waveguides





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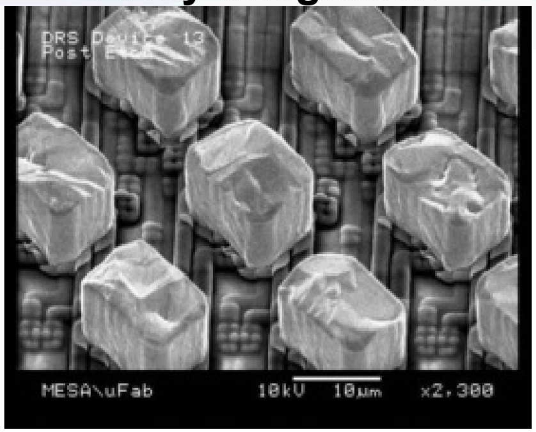
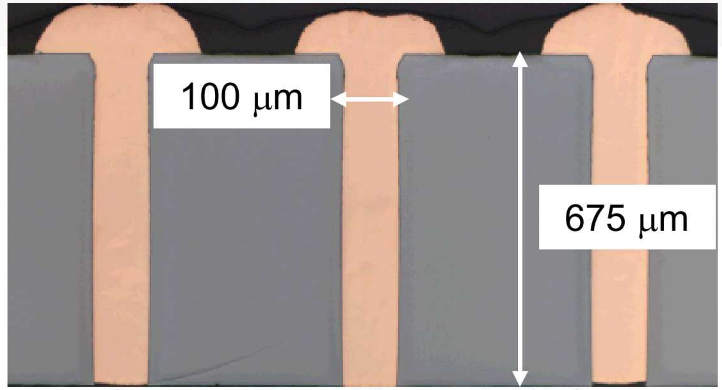
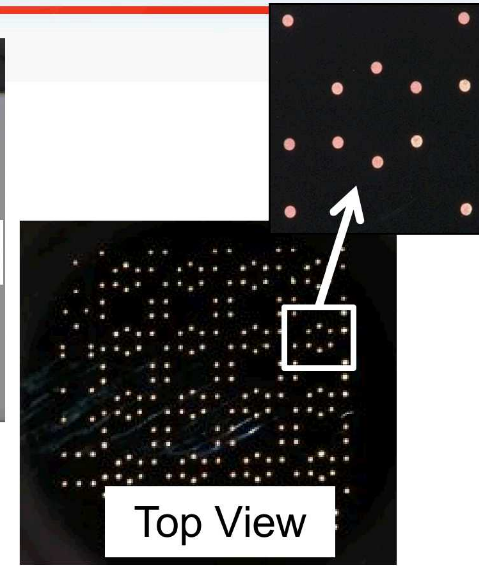
Indium Bumps for Focal Plane Array Integration

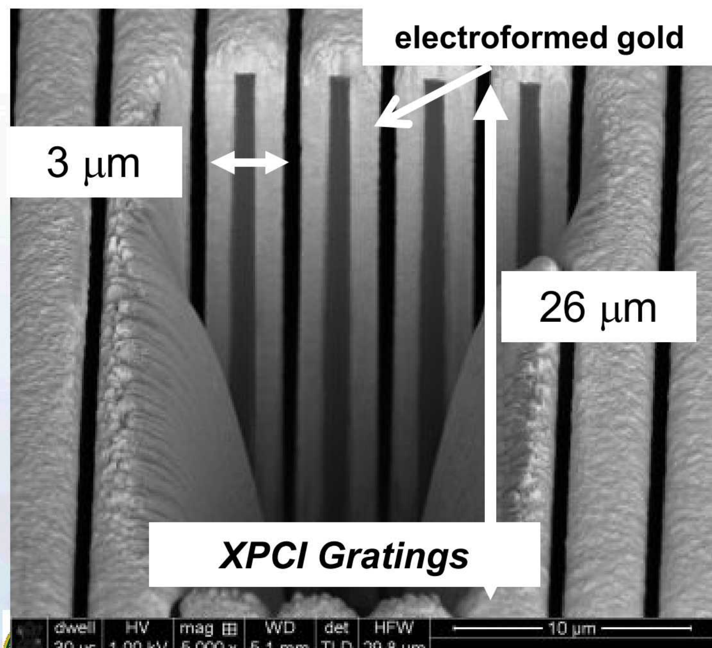


Copper TSV's



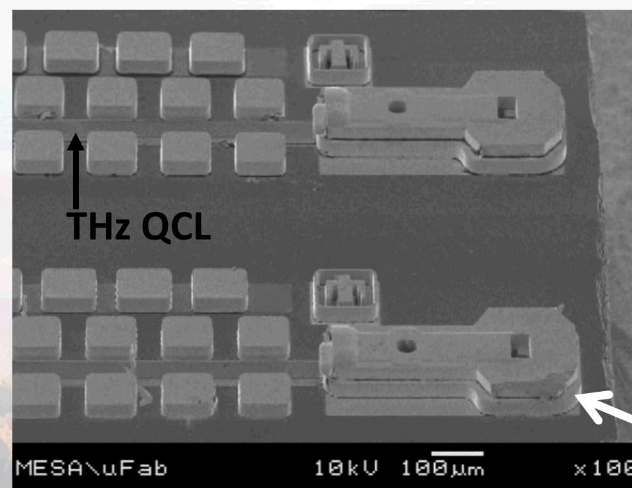
Copper Filled Through Wafer Silicon Vias

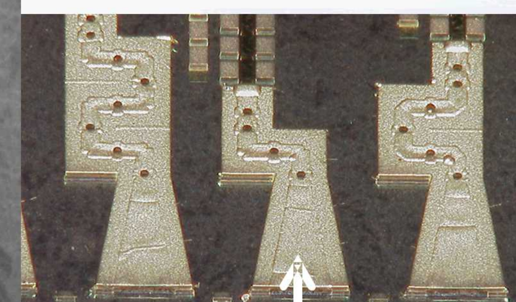




XPCI Gratings

3-D Integrated Gold THz Waveguides





2 layer electroformed Gold

Trapped ions as a quantum computing platform

Quantum computer

- **Superposition states:**
  - $0_a0_b+0_a1_b+1_a0_b+1_a1_b$

- **Entanglement (non-classical states)**

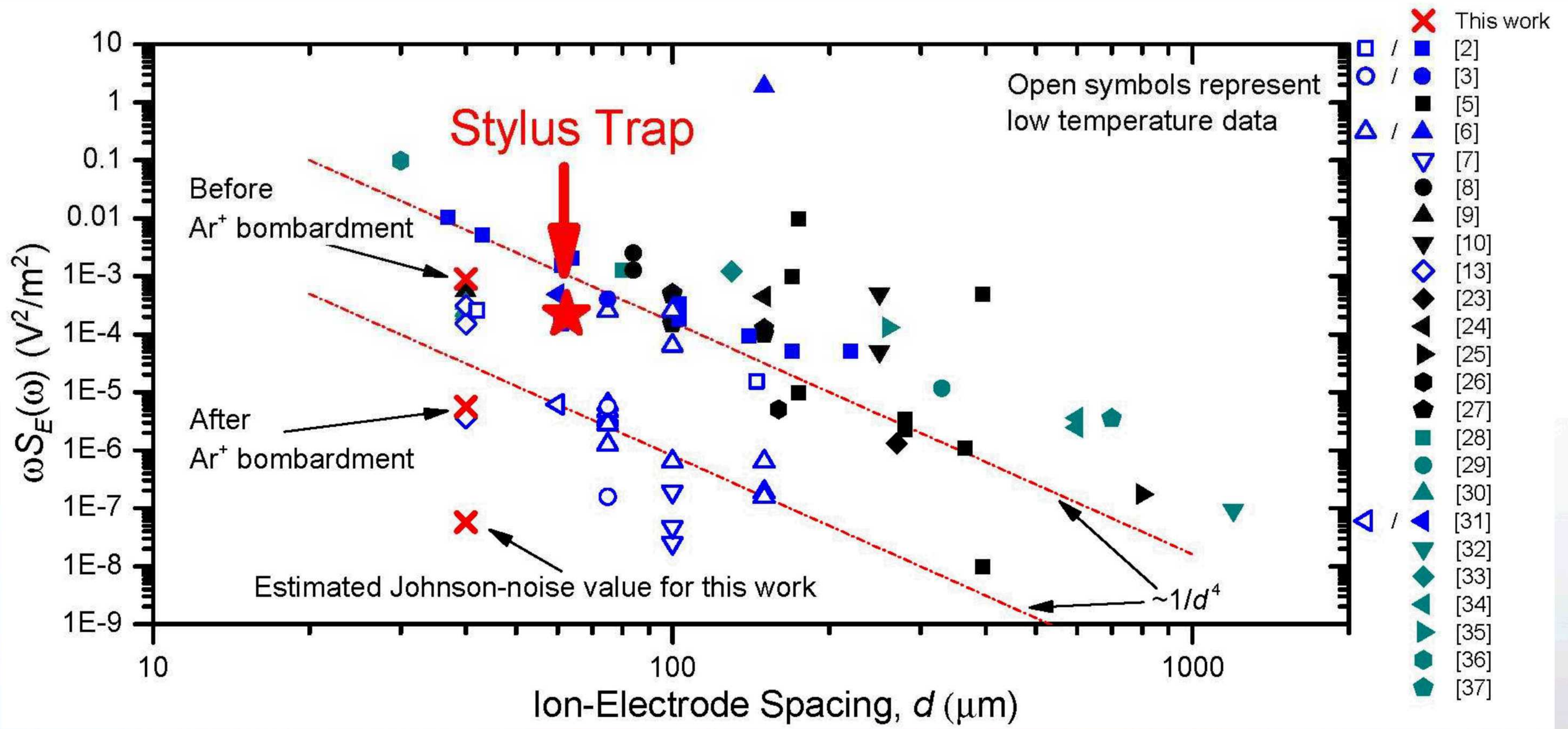
Classical computer

- Single states:
- 0_a0_b or 0_a1_b or 1_a0_b or 1_a1_b

- Only local operations

Exponential speedup for ***particular*** algorithms (most notably Shor's factoring algorithm)

Anomalous Heating Rate Experiments



National Institute of Standards and Technology, Boulder, CO 80305, USA David P. Pappas and David J. Wineland

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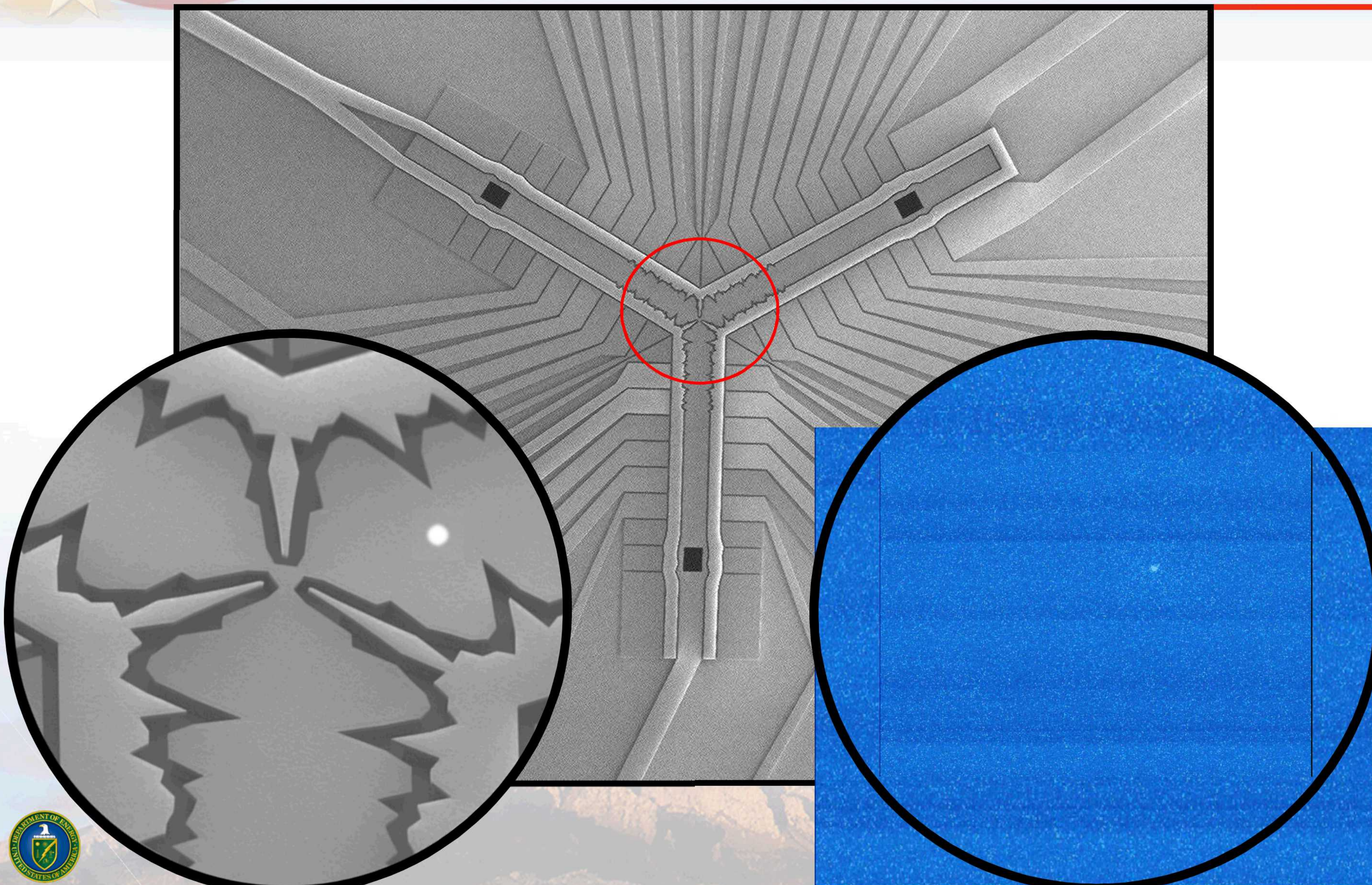
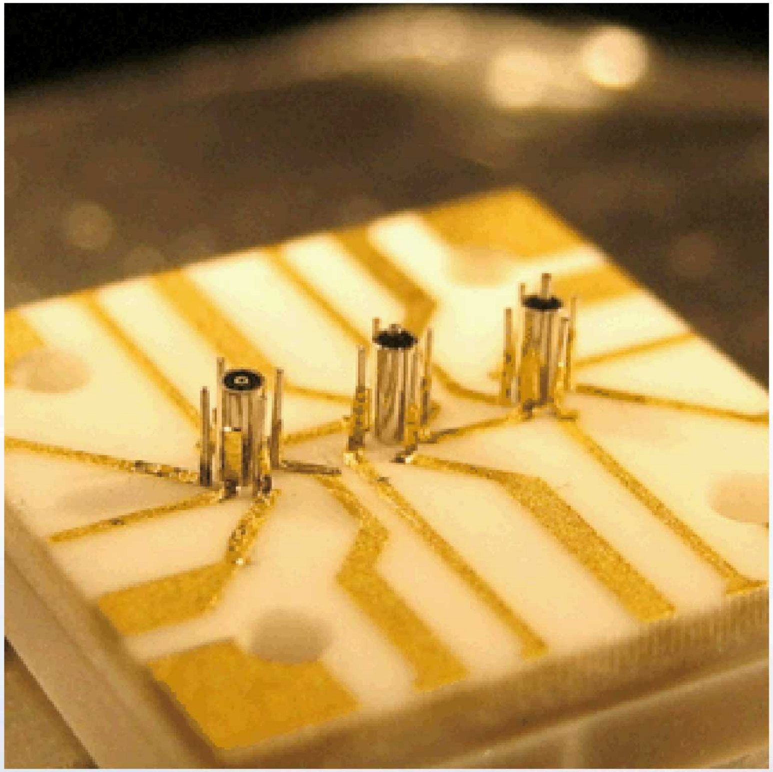
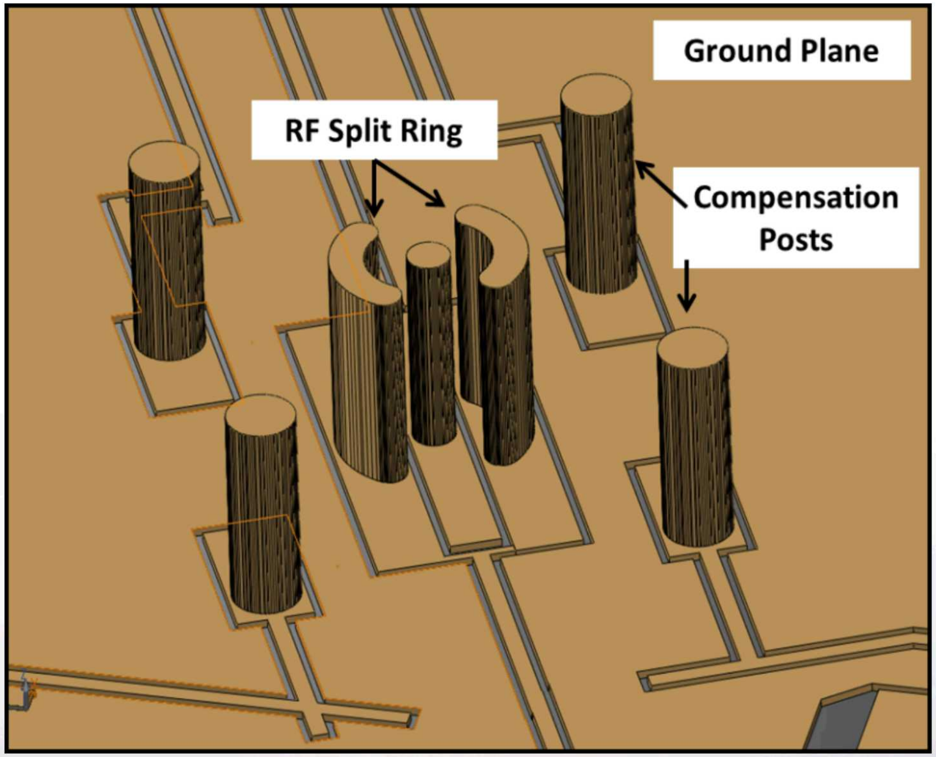
Y-Junction Trap shuttling through the junction



Stylus Ion Trap Background



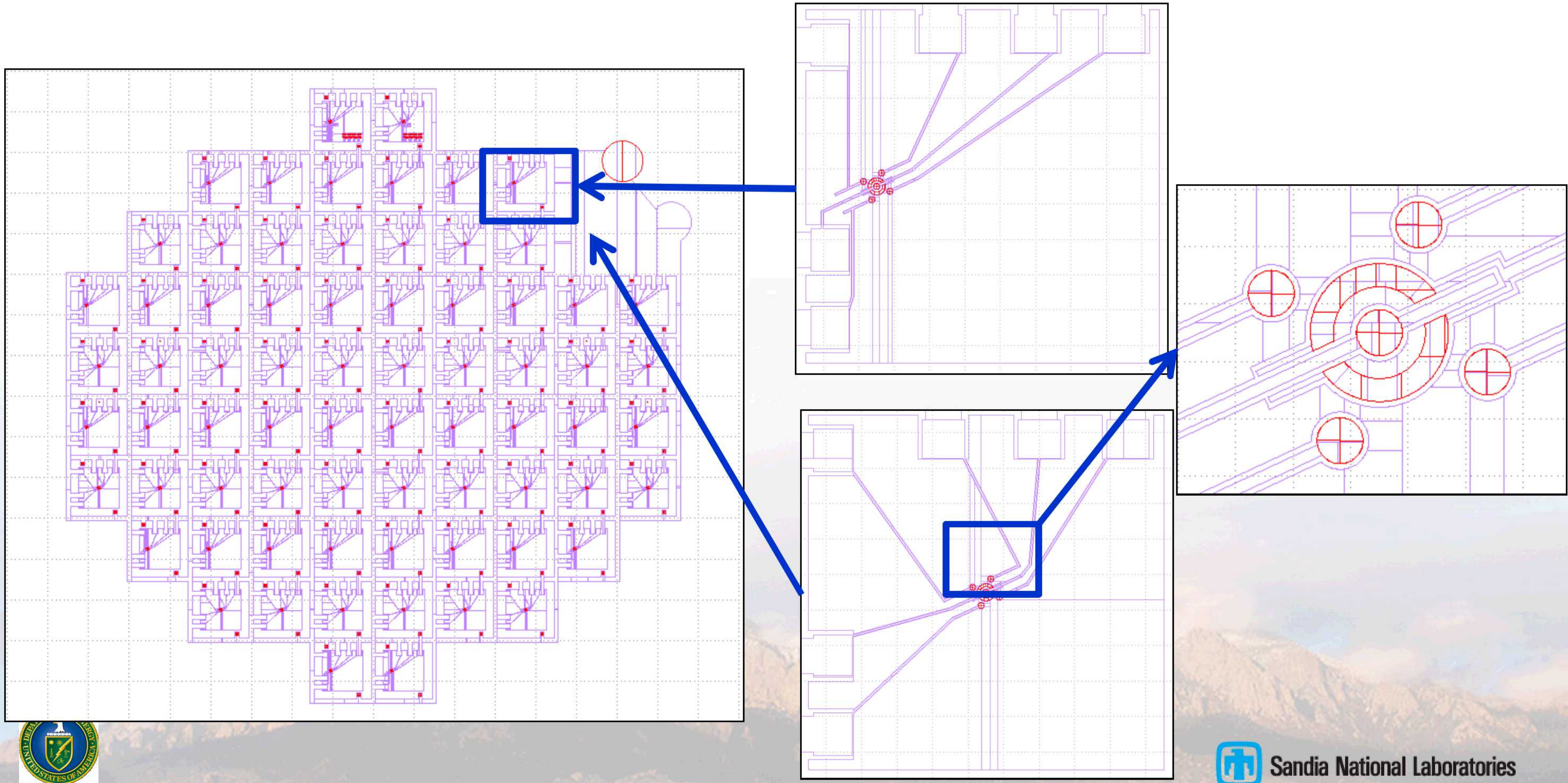
R. Maiwald, D. Leibfried, J. Britton, J. C. Bergquist, G. Leuchs, and D. J. Wineland, Nature Physics **5**, 551 (2009).



Model of Microfabricated Sylus Ion Trap

Generation 1 Mask Design

1. Layer 1 AZ 4330 postive resist
2. Layer 2 KMPR negative resist



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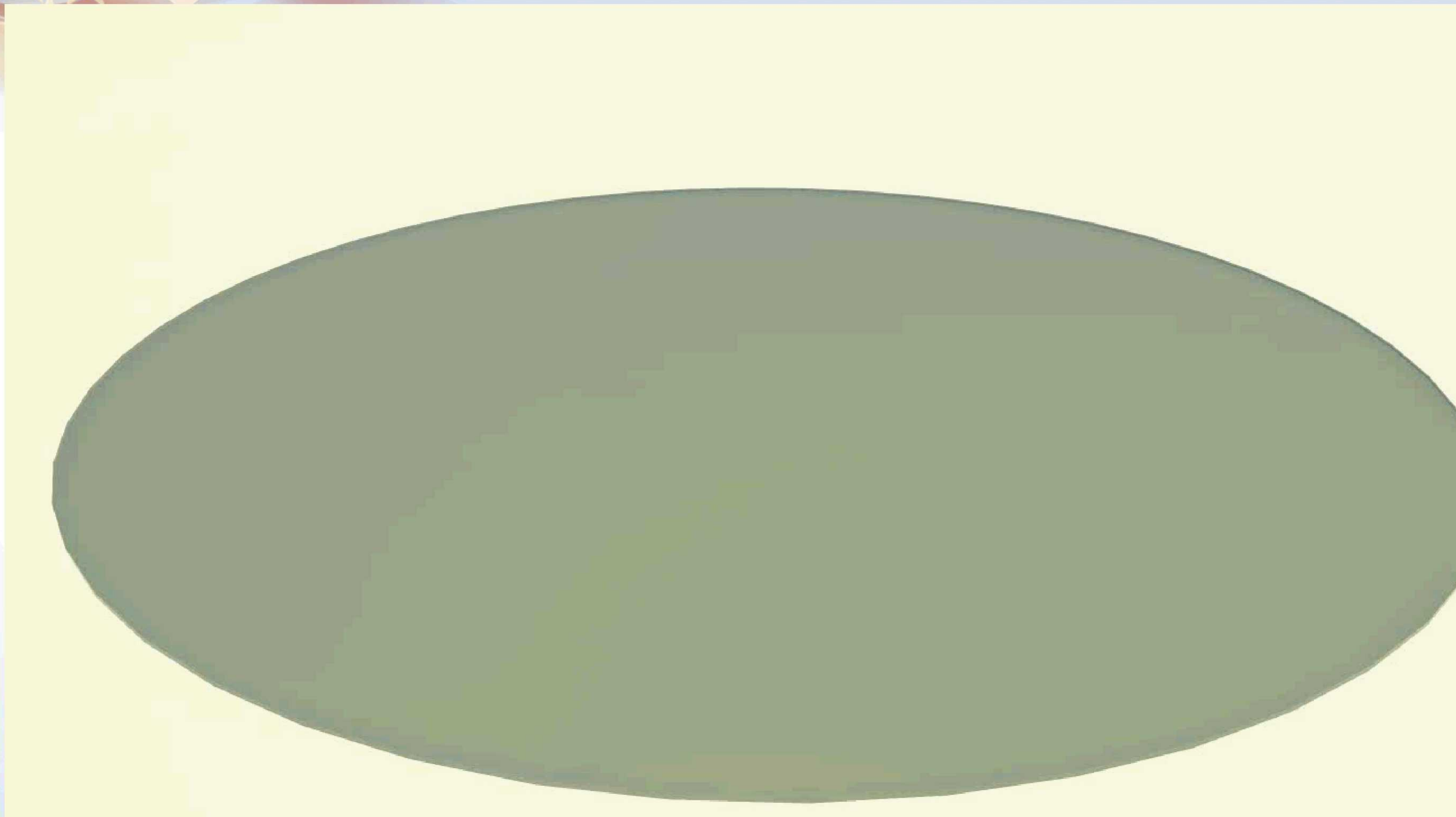

Animation courtesy of Hannah Louise Gillis, Carol Alynn Payne, Lozanne M Chavez, & Johanna Hartenberger.

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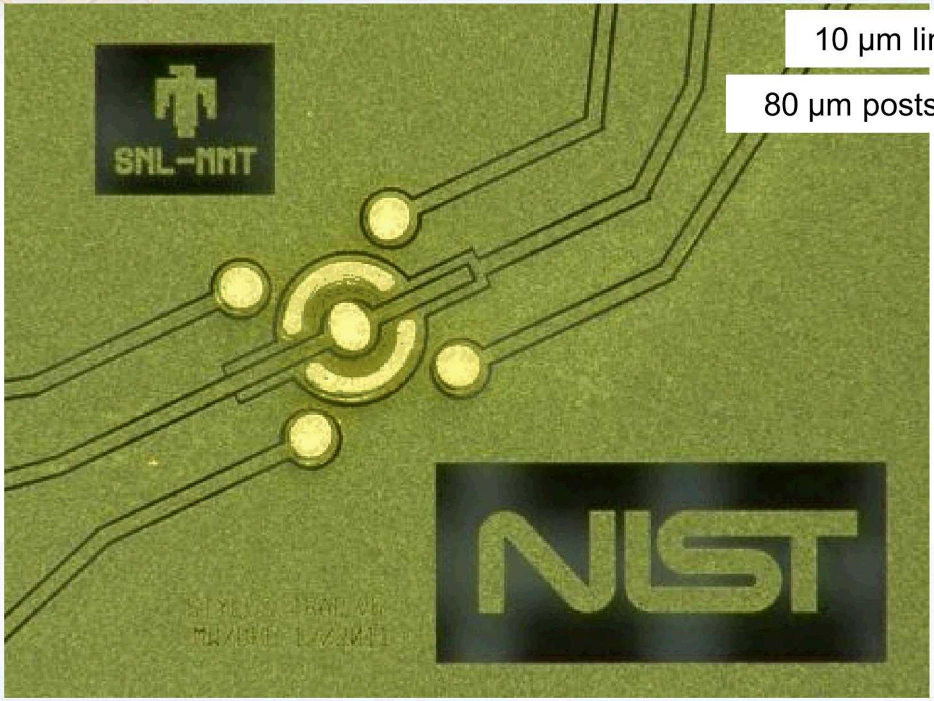
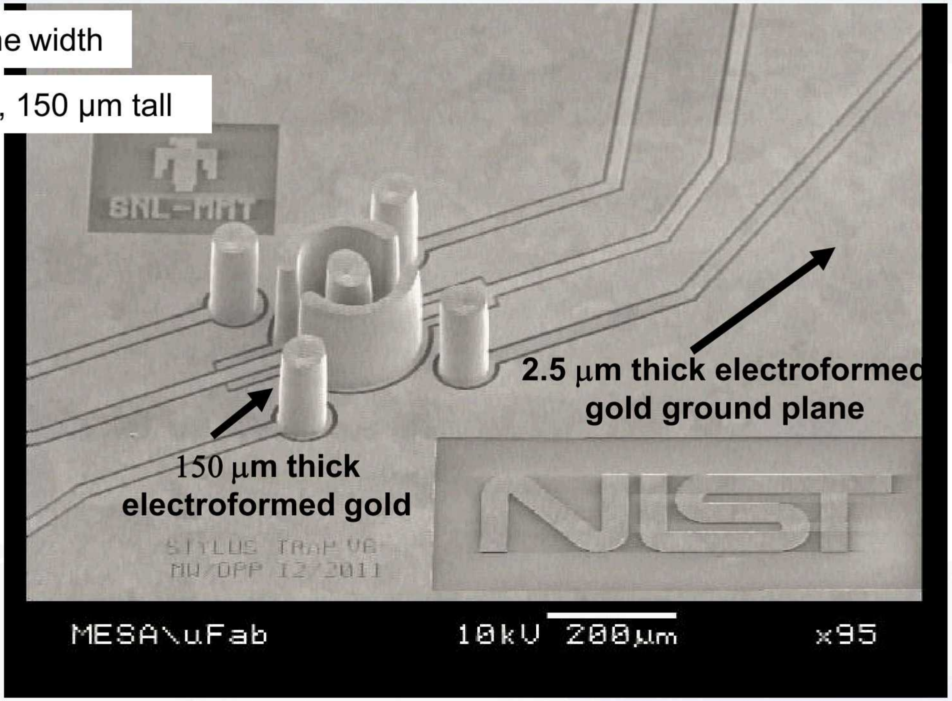
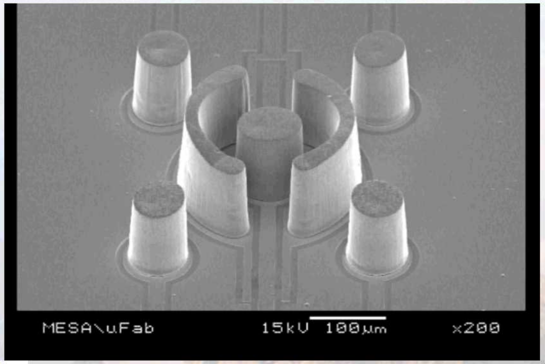
Generation 1 Mask Design

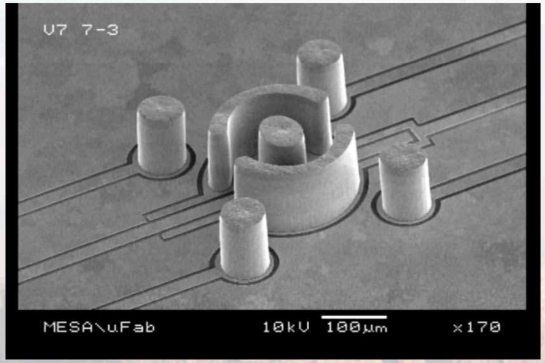
10 µm line width

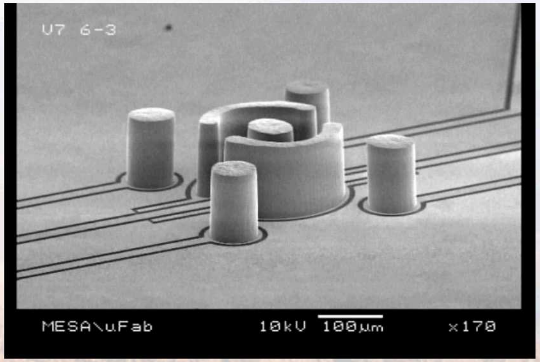
80 µm posts, 150 µm tall







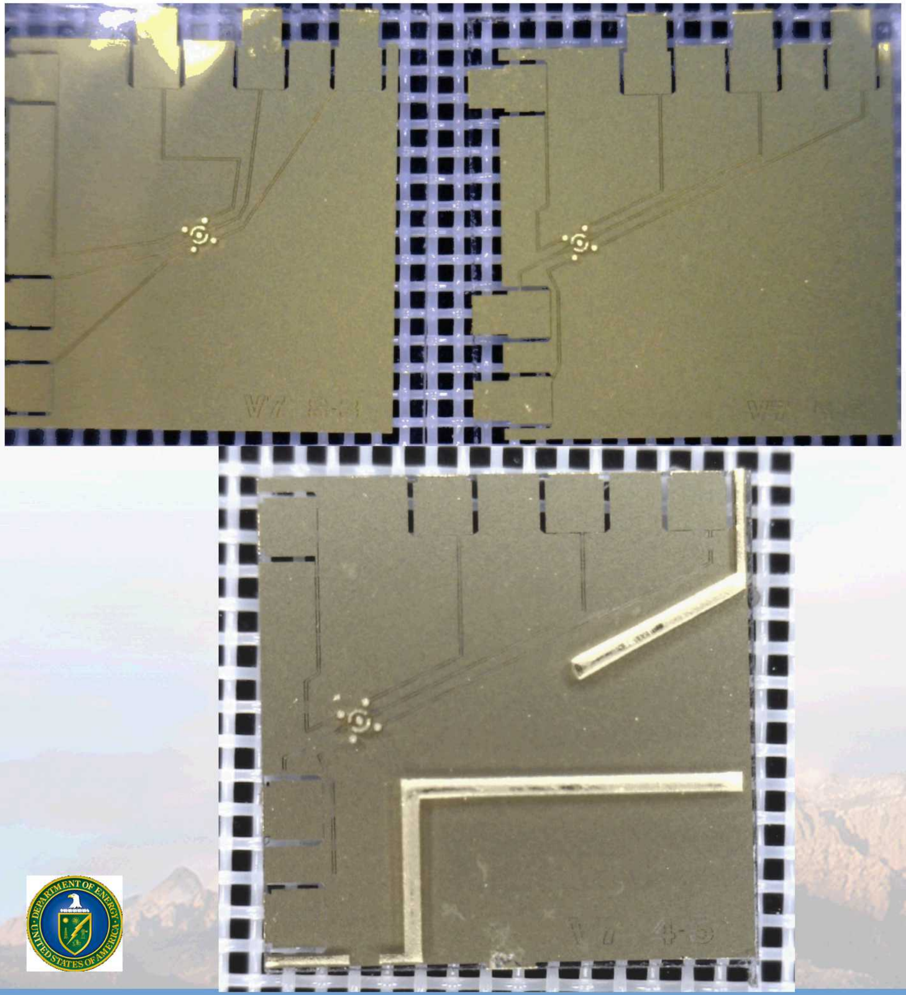




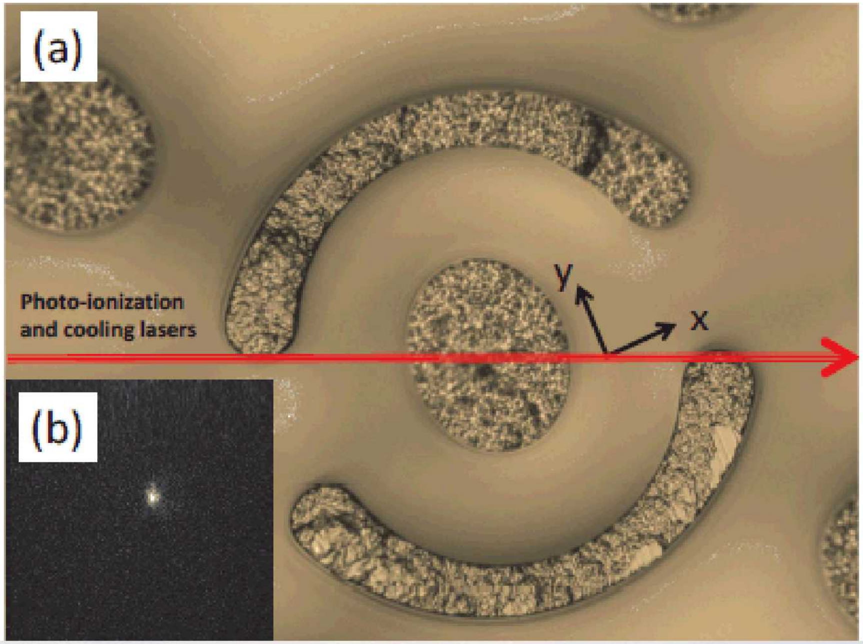
Generation 1

Delivery May 2012

Asymmetrical and center located traps

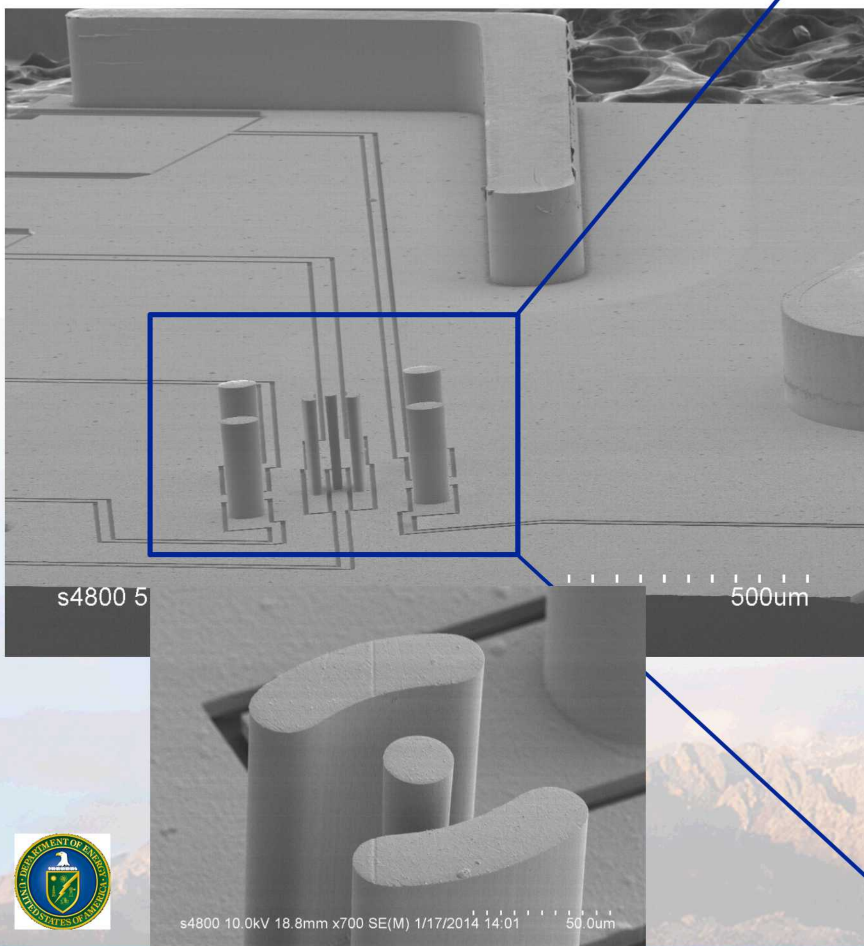


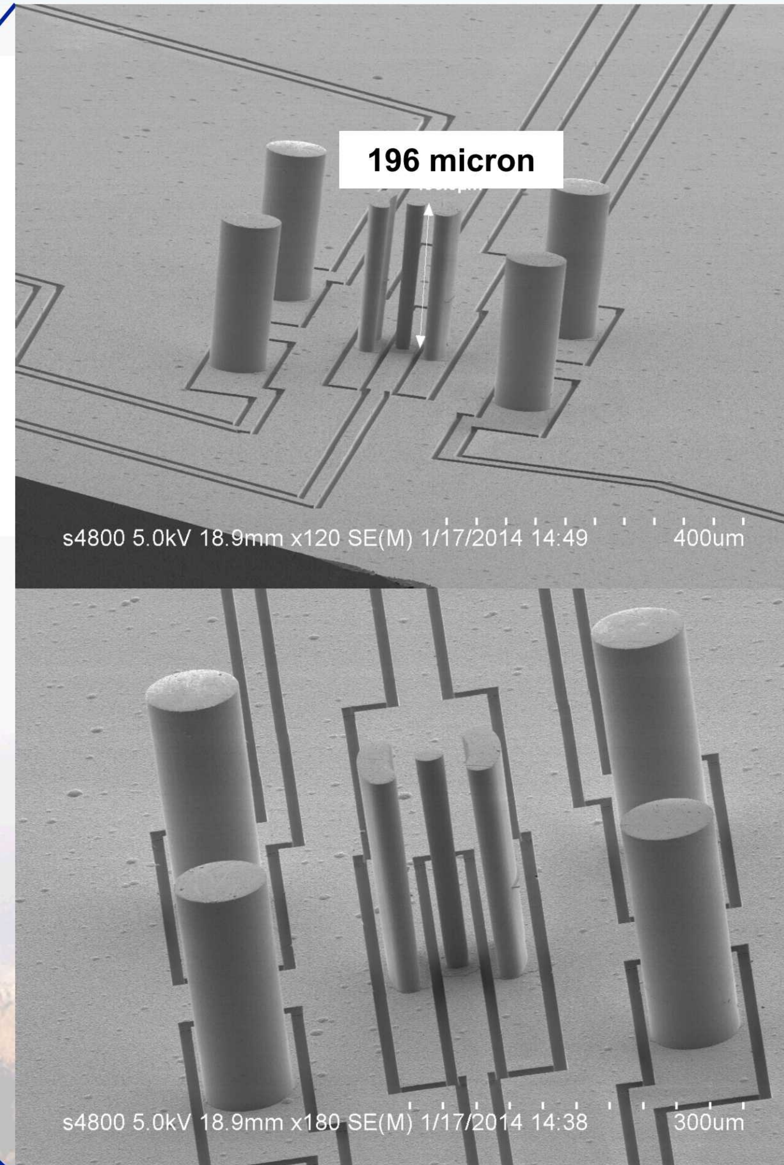
Resist swelling causing deformed structures



Generation 2 LIGA Traps

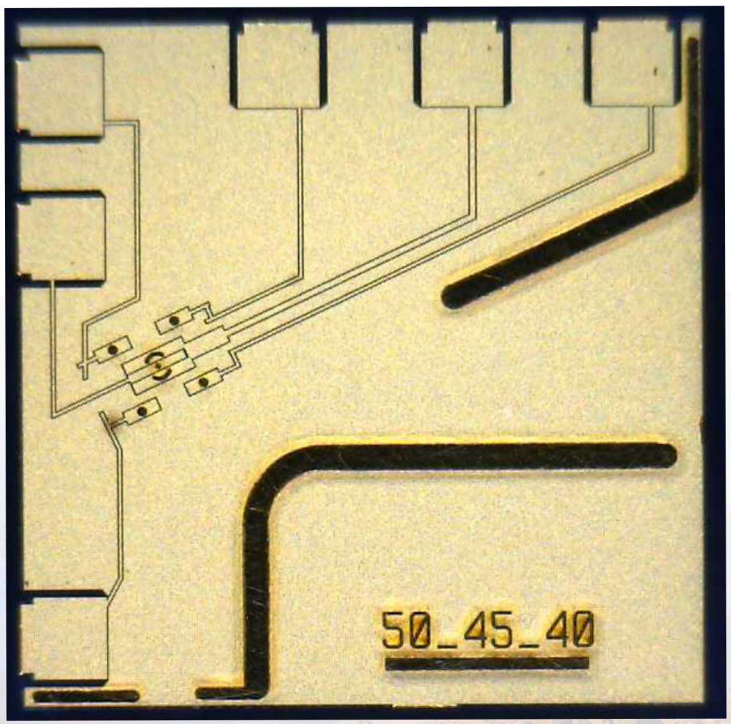
- 25-25-25 μm die
- 200 μm layer 2 feature height
- Improved sidewall profile
- Reduced PR swelling

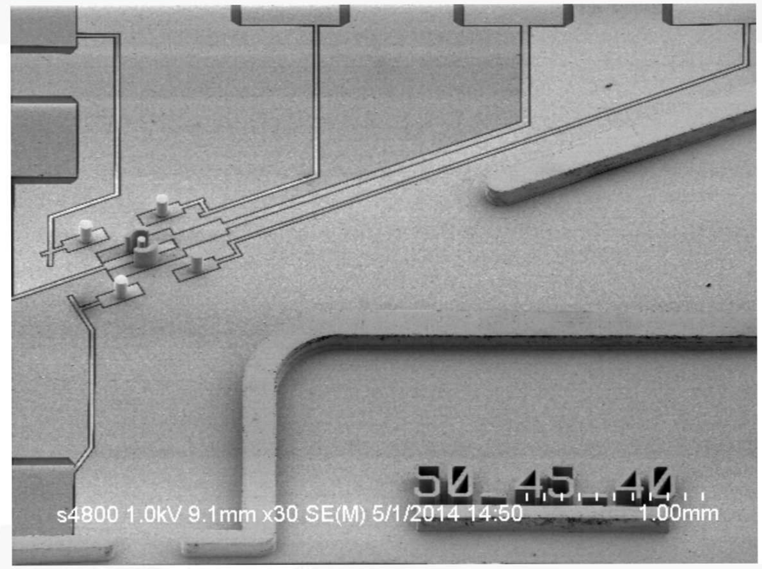


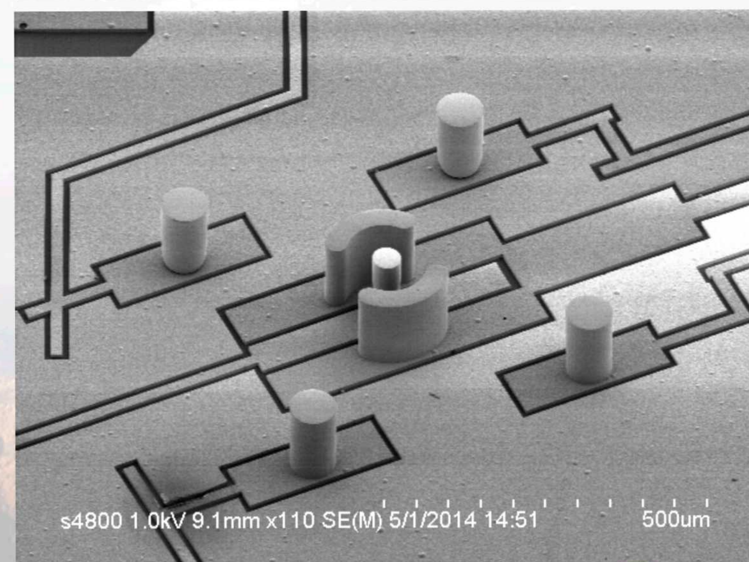


Generation 2 LIGA Traps

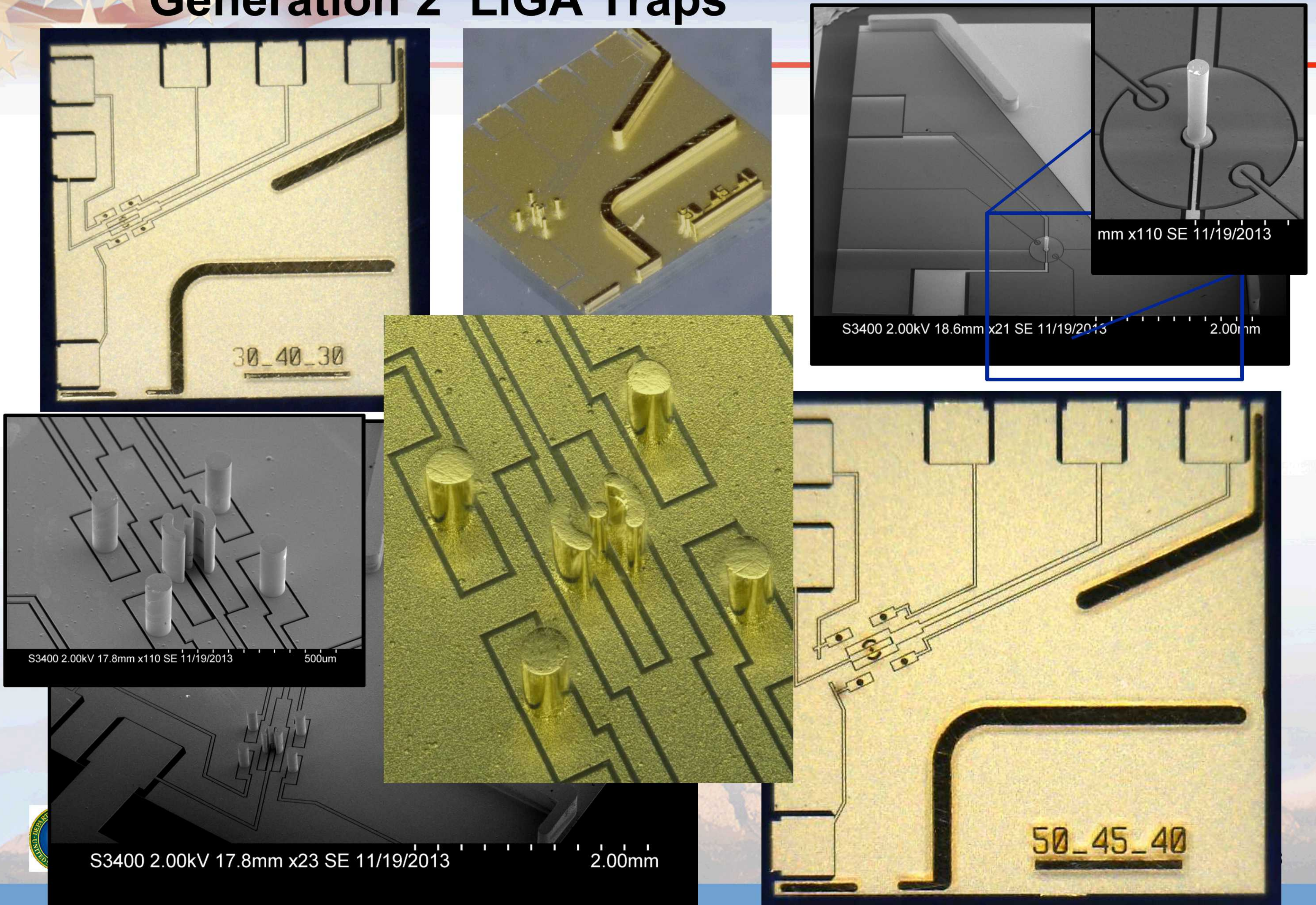
- M1- 10 μm
- M2- 150 μm
- 50-45-40 features



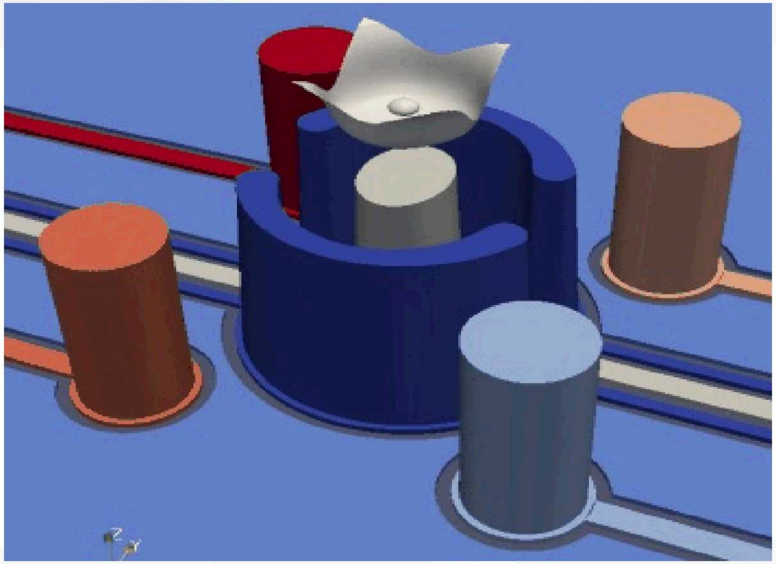




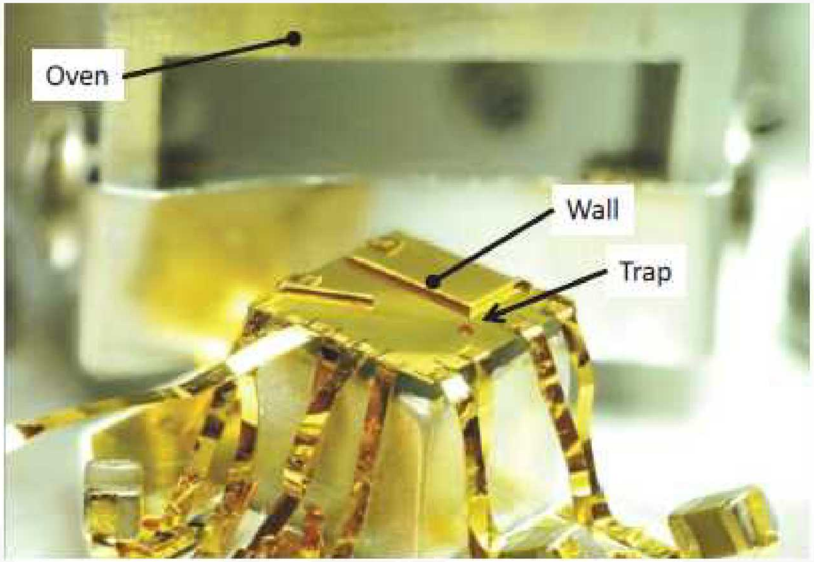
Generation 2 LIGA Traps

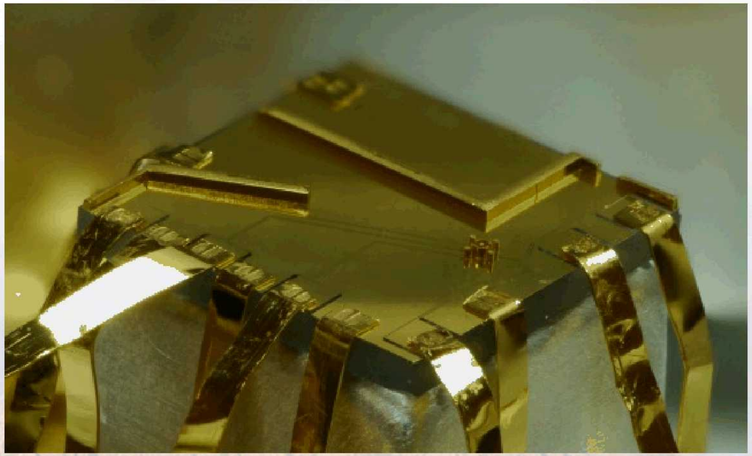


Microfabricated Stylus Ion Trap



BEM simulation results showing center ground post, RF biased ring, and four compensation posts. The two surfaces show example equipotentials for a 25Mg+.





	Measured values Nominal U_{trap}=100 V	BEM modeling results Fit U_{trap} = 85 V	
		Symmetric center electrode $A_{electrode}$=0	Asymmetric center electrode $A_{electrode}$=0.11
Ion height (μm)	60(15)	64.2	62.2
Well depth (meV)	Not measured	86	95
x motional frequency (MHz) f_x	4.03(5)	3.35	4.09
y motional frequency (MHz) f_y	4.17(5)	4.078	4.34
z motional frequency (MHz) f_z	8.15(5)	7.58	8.63
x-y frequency asymmetry, A_f	0.017(9)	0.194	0.031

Micro-fabricated Stylus Ion Traps, 2013 AIP, Review of Scientific Inst.
C.L. Arrington, K.S. McKay, D.P. Pappas, D.J. Wineland,

“Palm”
Controller

Desorb Felt

IMS

Absorb Felt

Sample Inlet

Dryer

Batteries

Motors, Pumps
Flow Control

Dopant Gas

µ HOUND™

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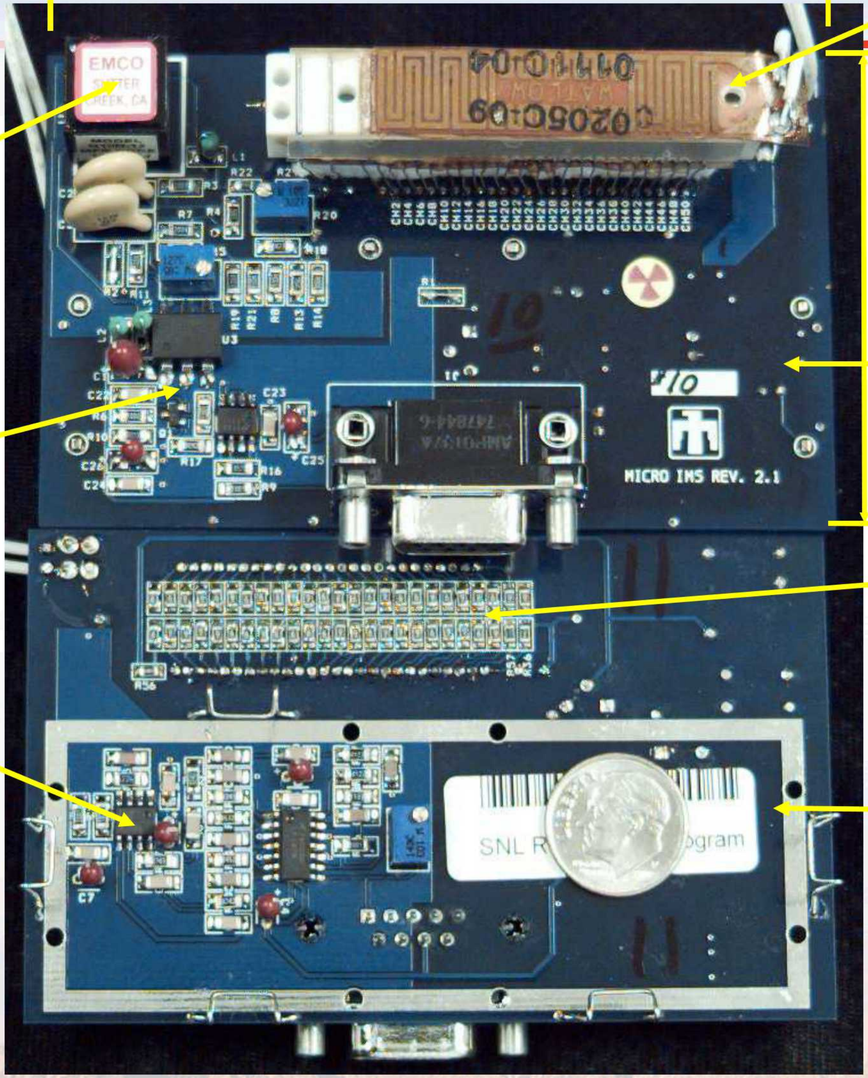
10 cm

IMS Drift Tube

High
Voltage
Power
Supply

6 cm



Top of Board

High Voltage
Switching
Electronics

Voltage
Divider

High Sensitivity

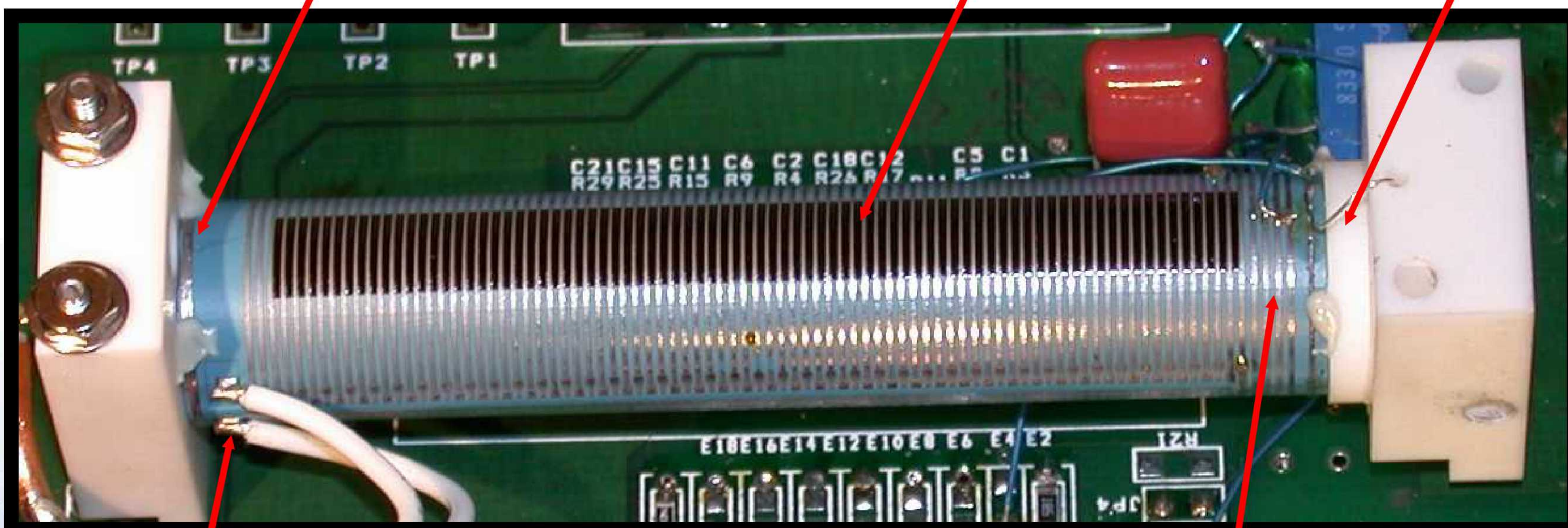
Detection Electronics

Bottom of Board

Target

Integral Resistors

Am_{241}



Integral Heater

Apertures/ Control Grids

1 cm

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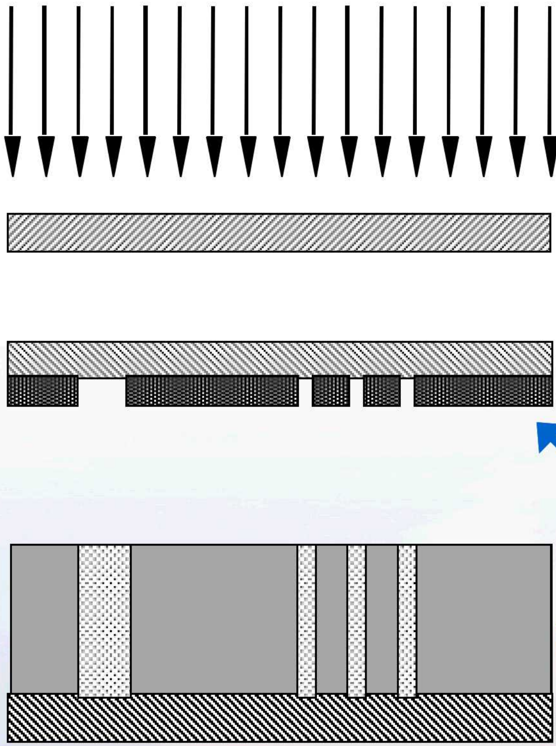
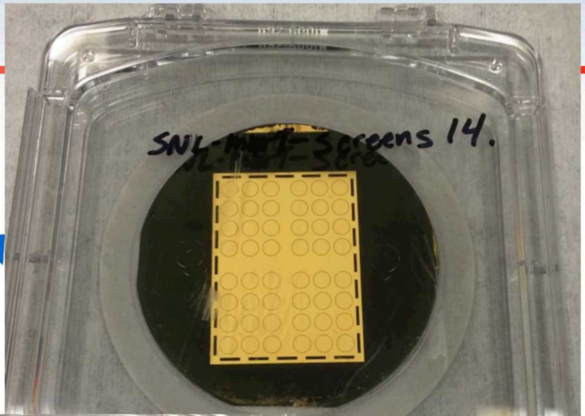
Microhound LIGA Screens Fabrication

LIGA Fabrication
Process flow

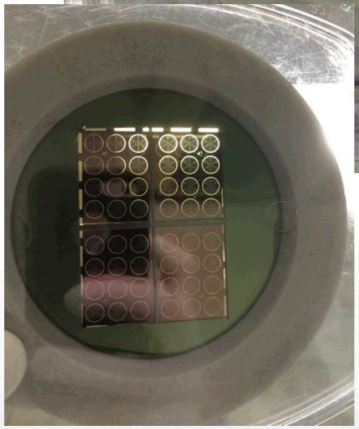


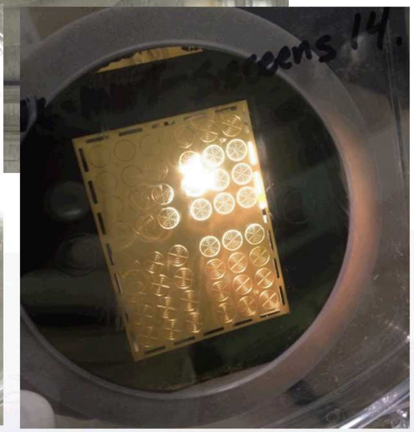
Front
view

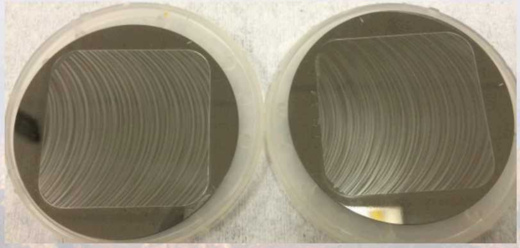


Backside

view



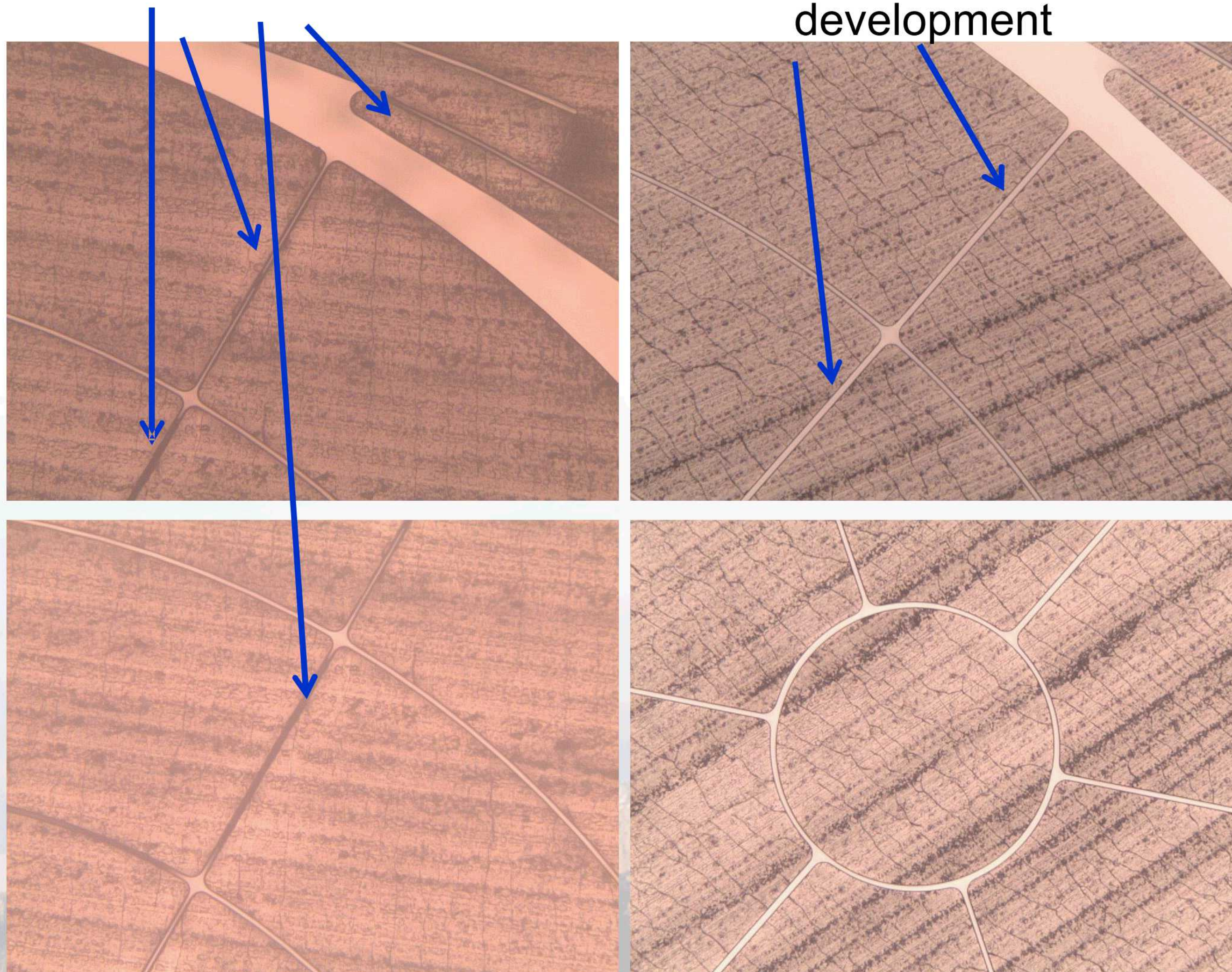




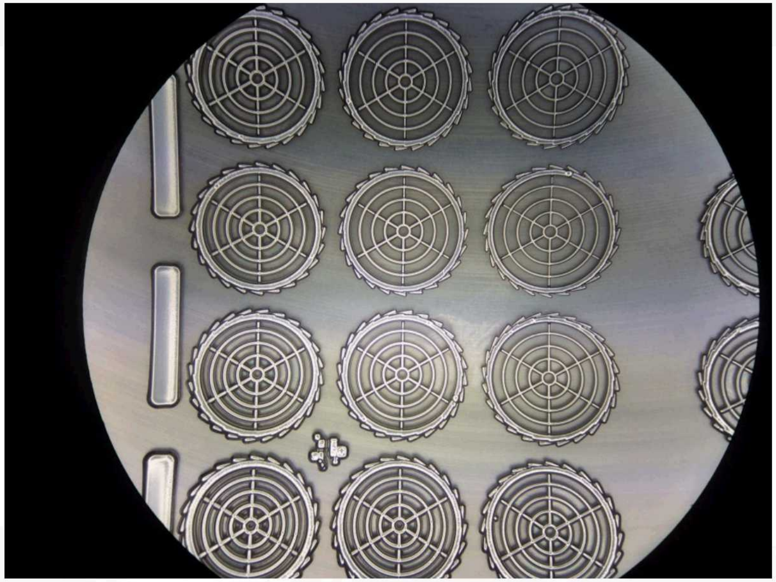
Improved 10 μm PMMA mold with higher x-ray dose

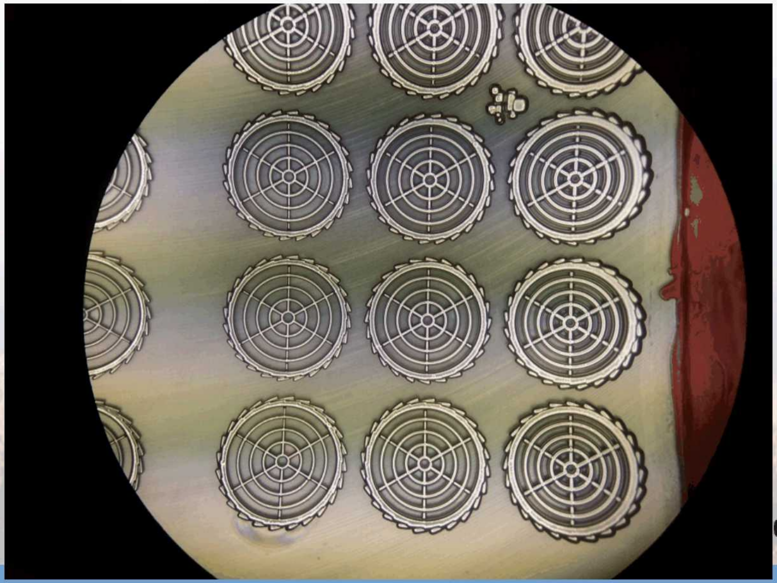
Dark regions show undeveloped PMMA

Higher x-ray dose with improved development

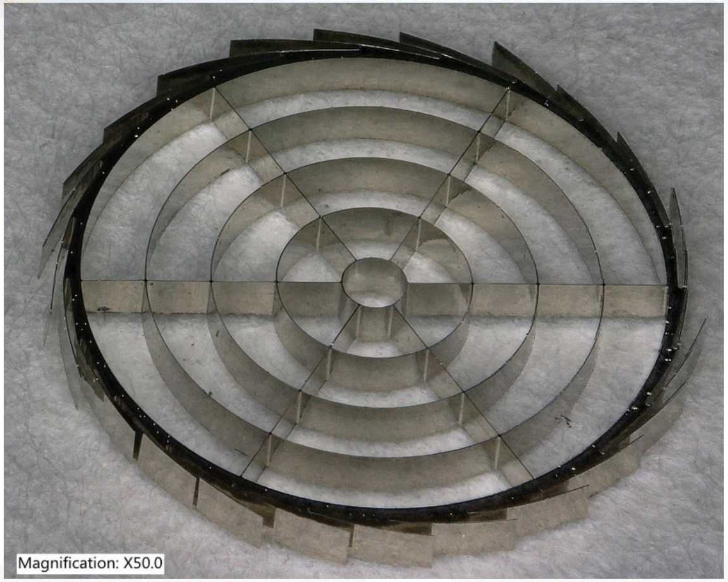


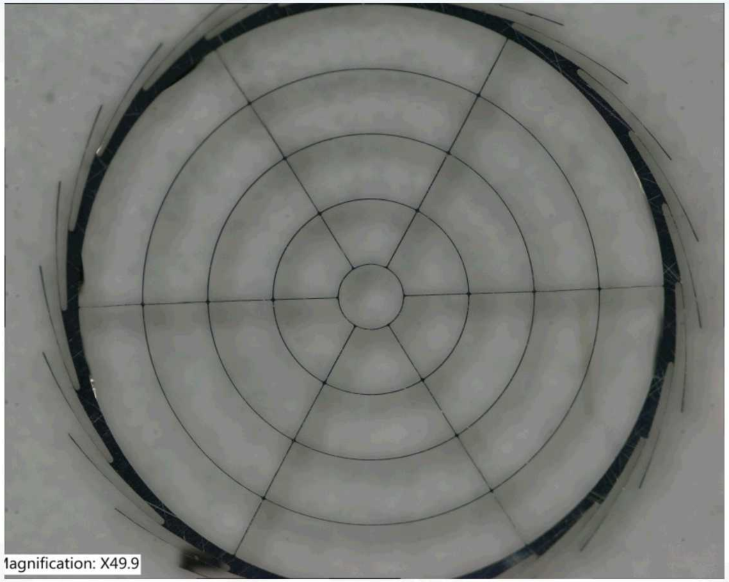
After Nickel Plating over the PMMA mold

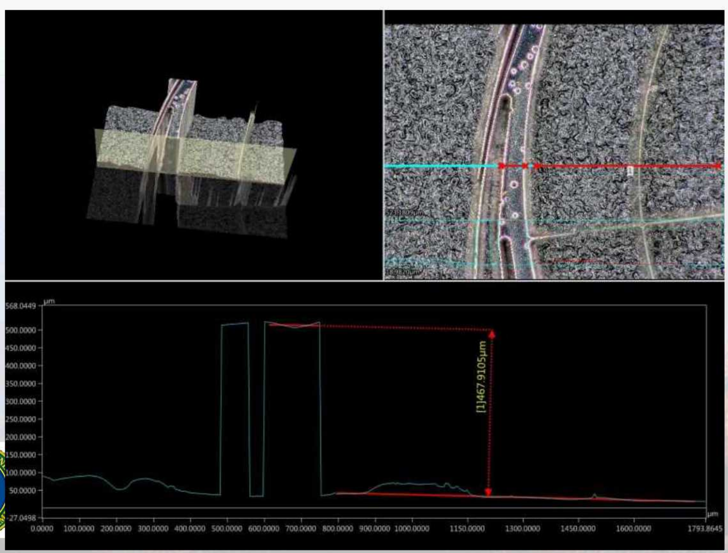


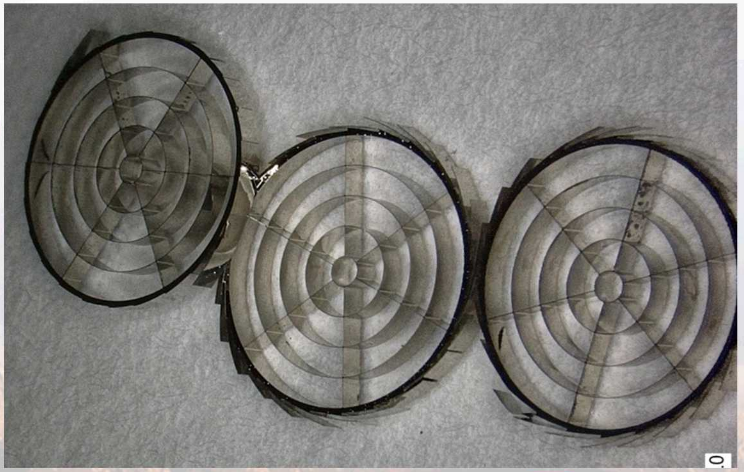


After PMMA removal and Undercut seed layer

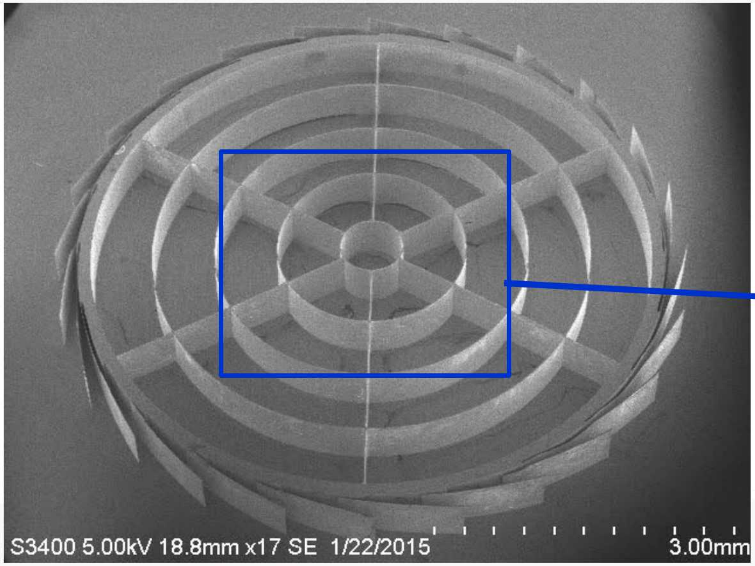


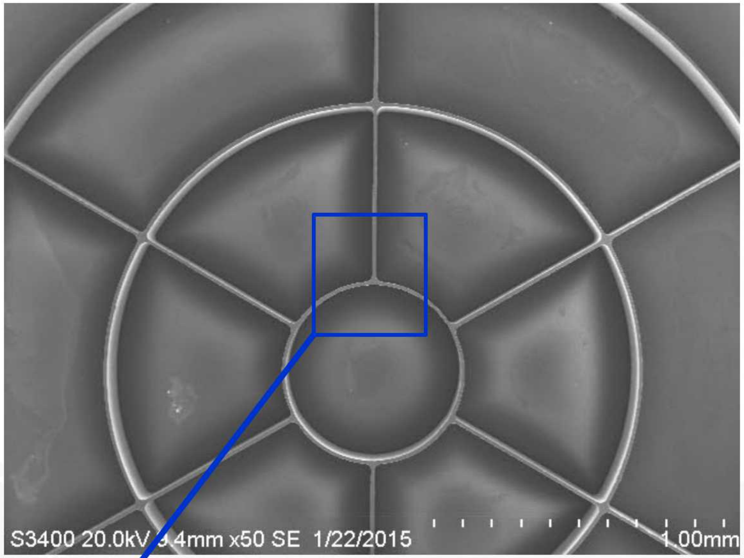


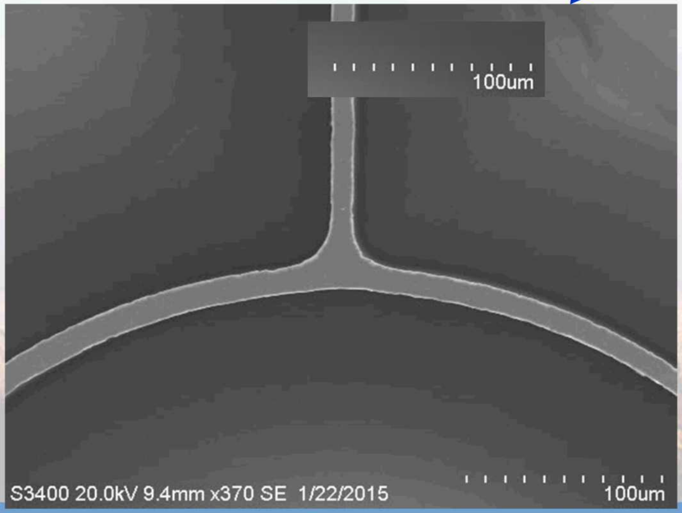




SEM images

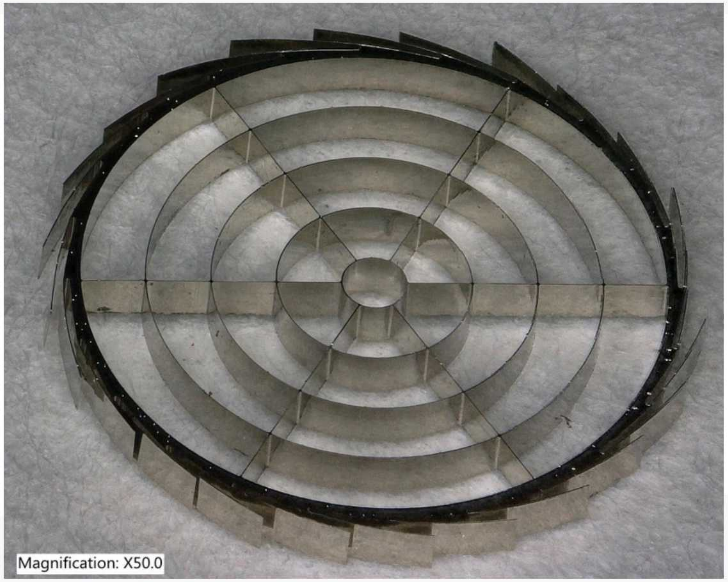




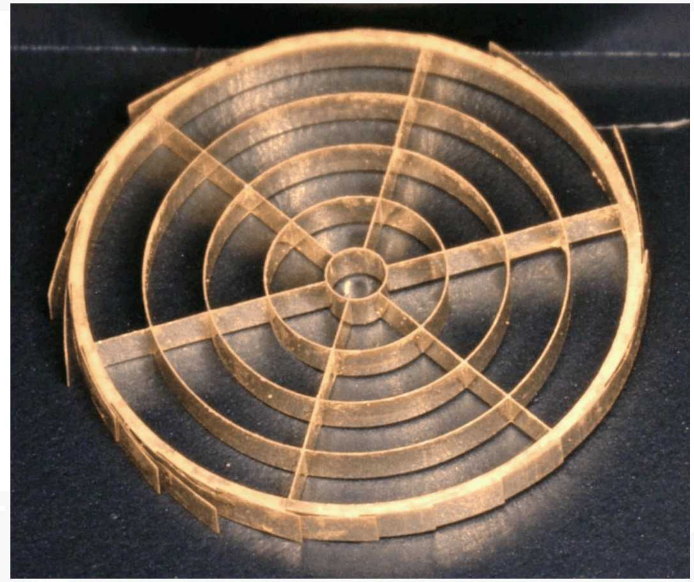


Top View

Gold plating



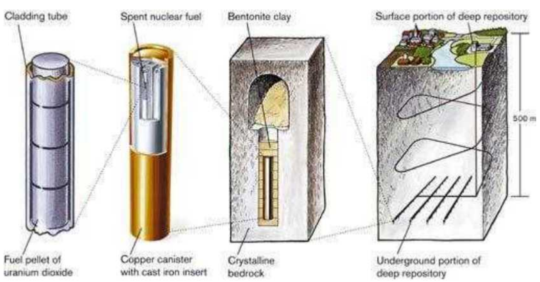
LIGA fabricated Nickel screen



After gold plating

Unique Harsh Environment Tagging Applications

Tags for Nuclear Waste/UF6 Cylinders



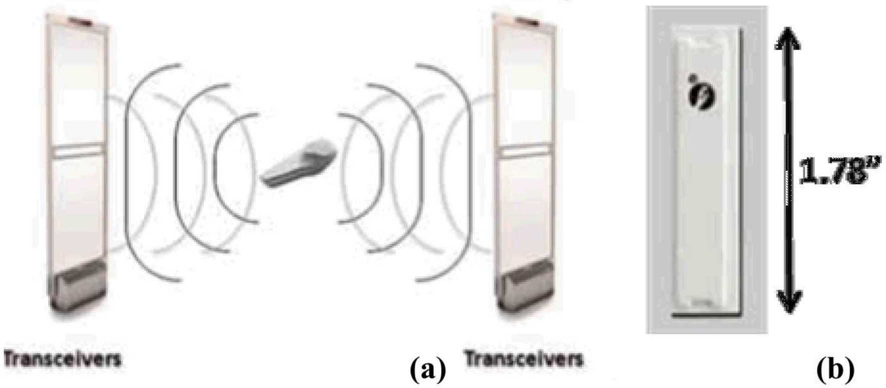
Tagging of copper canisters for spent fuel repositories - 1st NNSA insertion opportunity as part of Next Generation Safeguards Initiative (NGSI)

Component Identification inside Transportation Vehicles

Tagging Medical Radioactive Material

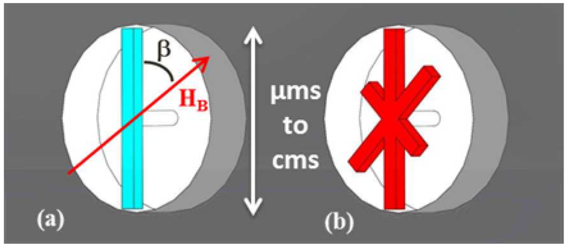
Magnetic Tags Overview

"Dumb Tag"



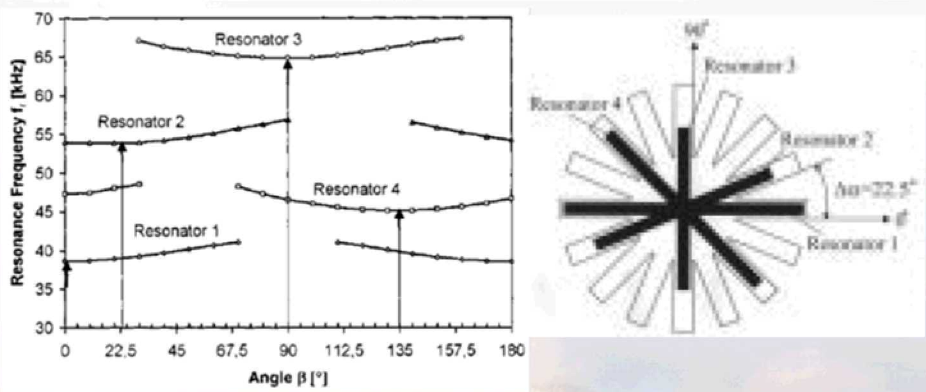
a) magnetic dipole antenna interrogation zone
b) magnetoelastic tag in plastic package

"Smart Tag"



a) Single frequency resonator
b) Multi-Frequency resonator (3)

$$f_r = \frac{1}{2L}\left[\sqrt{\frac{\rho}{E_0} + \frac{9\lambda^2{}_S\rho\left(\left(|H_B|\cos(\beta)\right)\right)^2}{J_s H_A{}^3}}\right]^{-1}$$



- Used to prevent theft in retail stores
- Operates via Joule magnetostriction, $\lambda_S = \Delta L/L$
- Generates an AC magnetic response signal when subjected to an externally applied AC magnetic interrogation signal
- Single frequency devices – can only convey information that a tag is magnetically activated (limited utility to this simple function)
- Made from strips of an amorphous magnetic material such as METGLAS™ ($Ni_{40\text{-}50}Fe_{40\text{-}50}Mo_{5\text{-}10}B_{1\text{-}5}$), with low magnetostriction (λ_S = 12 ppm)

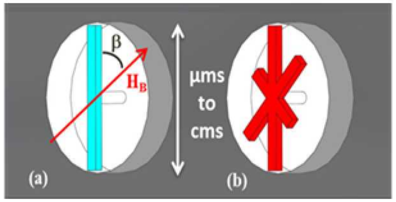
M. Arndt and L. Kiesewetter, "Coded labels with amorphous magnetoelastic resonators," Magnetics, IEEE Transactions on, vol. 38, pp. 3374-3376, 2002.

Controlling CoFe Electrodeposited Film Properties for Improved Magnetostriction

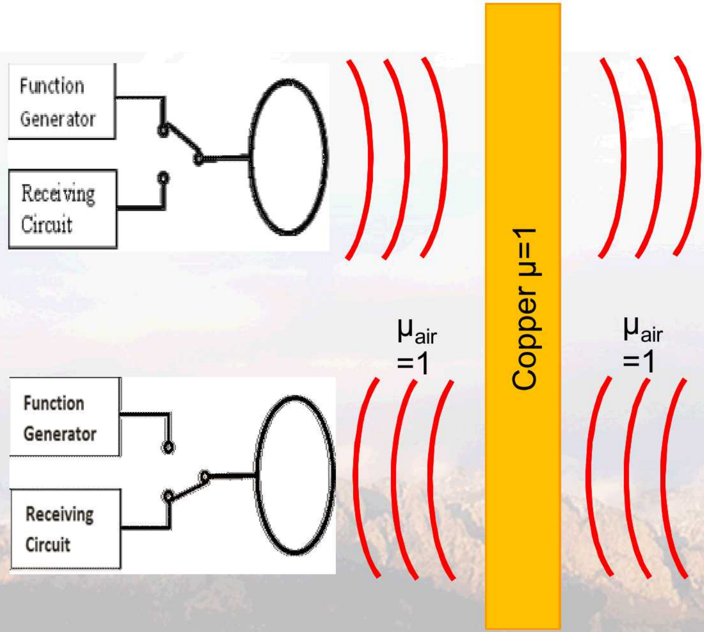
- **High magnetostrictive films for increased resonance signal amplitude**
  - MEMS applications
  - Sensors

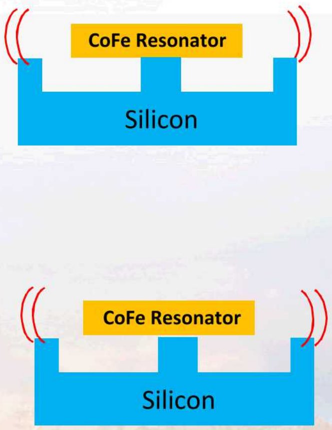
$$f_r = \frac{1}{2L}\left[\sqrt{\frac{\rho}{E_0} + \frac{9\lambda_{sat.}{}^2\rho\left(\left(|H_B|\cos(\beta)\right)\right)^2}{J_s H_A{}^3}}\right]^1$$

Magnetostrictive Sensors



a) Single frequency resonator
b) Multi-Frequency resonator

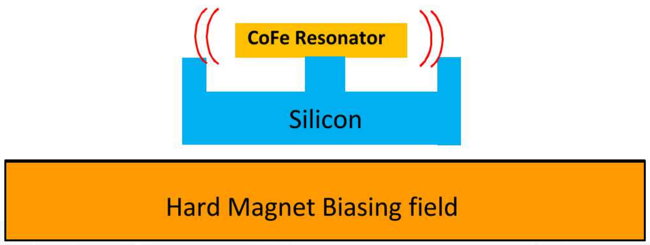




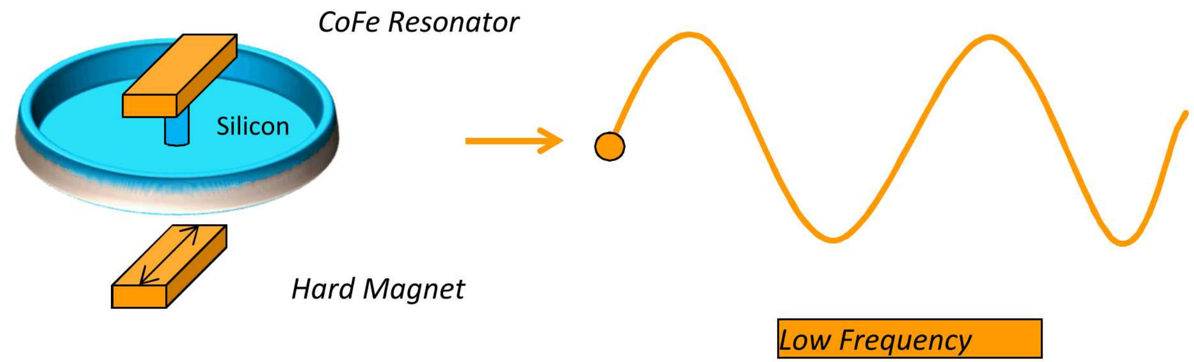
Cross section view

Copper Fuel storage canister for Spent nuclear fuel

CoFe resonator change in orientation

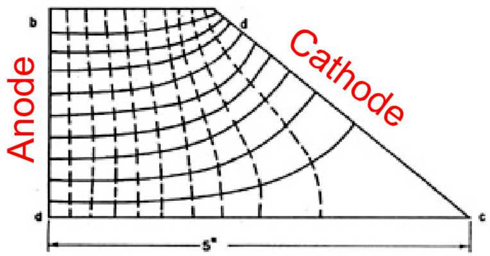


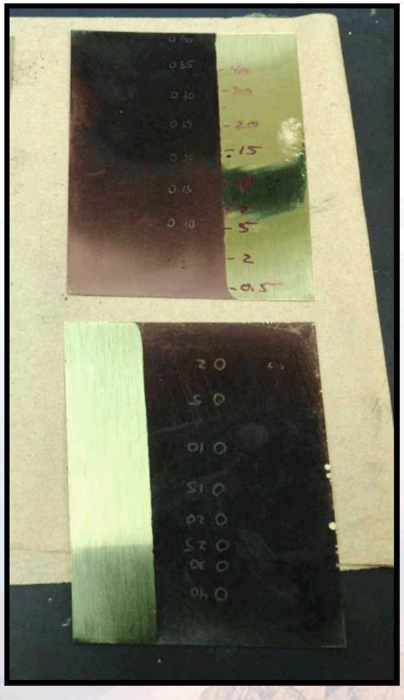
Cross section view



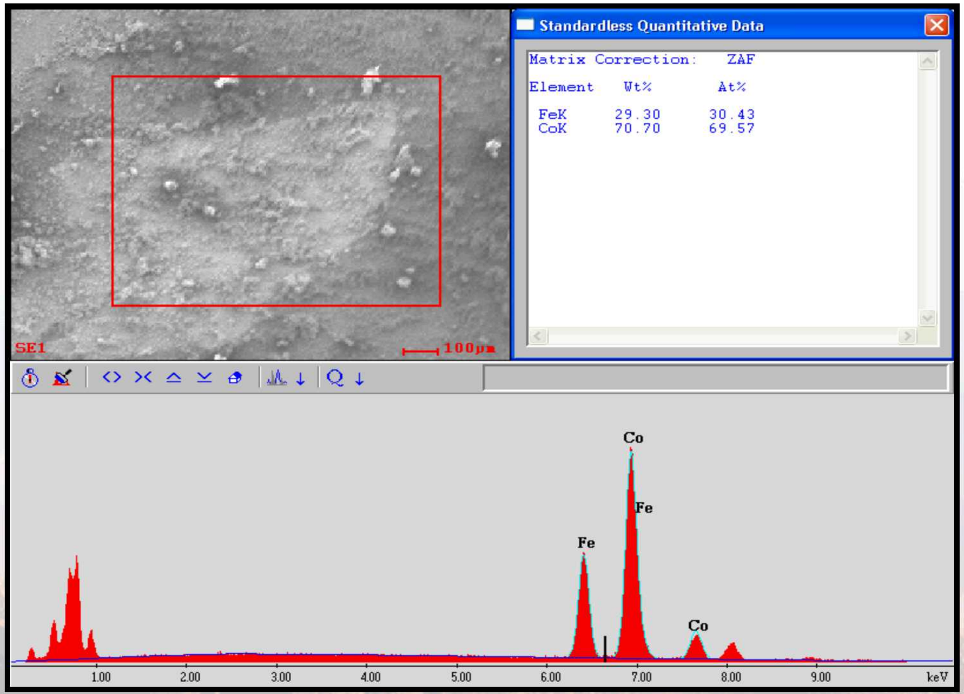
3D view

Finding the Desired Stoichiometry





- **Hull cell test used to quickly evaluate the affect of current density on stoichiometry**
- Energy-dispersive spectroscopy (EDS) used to evaluate composition
- 40 mA/cm^2 repeatedly produced $Co_{0.7}Fe_{0.3}$ ratio as identified as 'giant magnetostriction' by cite Hunter *et al* (Nature 2011)



*Hunter, D., et al., *Giant magnetostriction in annealed Co(1-x)Fe(x) thin-films.* Nat Commun, 2011. 2: p. 518.

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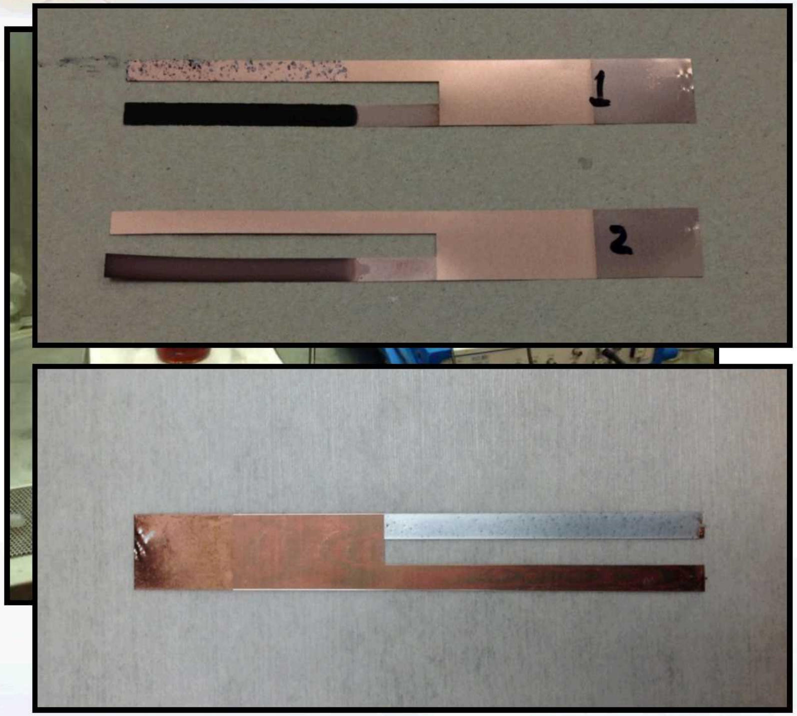
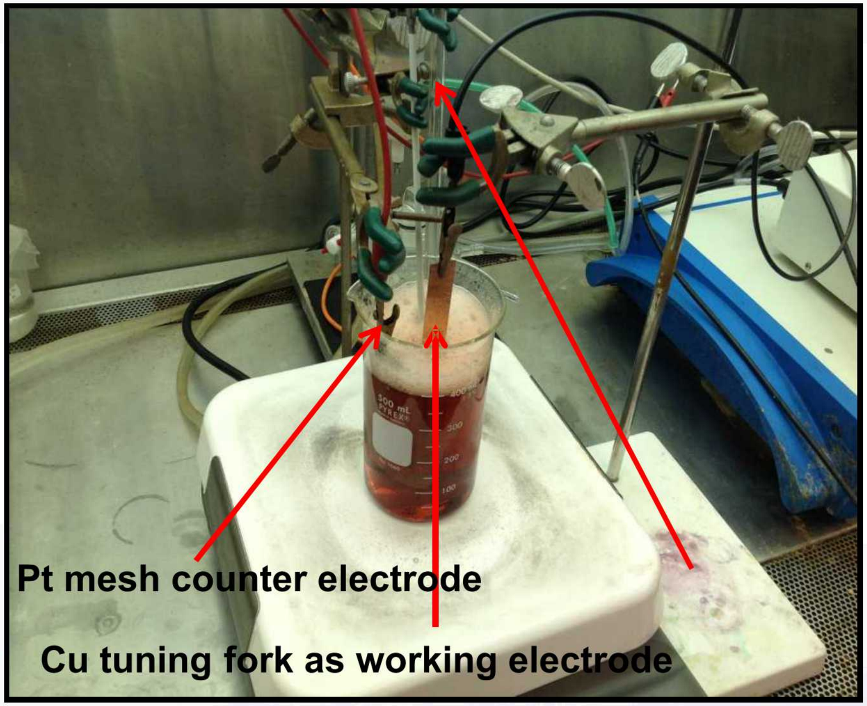
Plating Setup for Deposition on Cu Tuning Fork



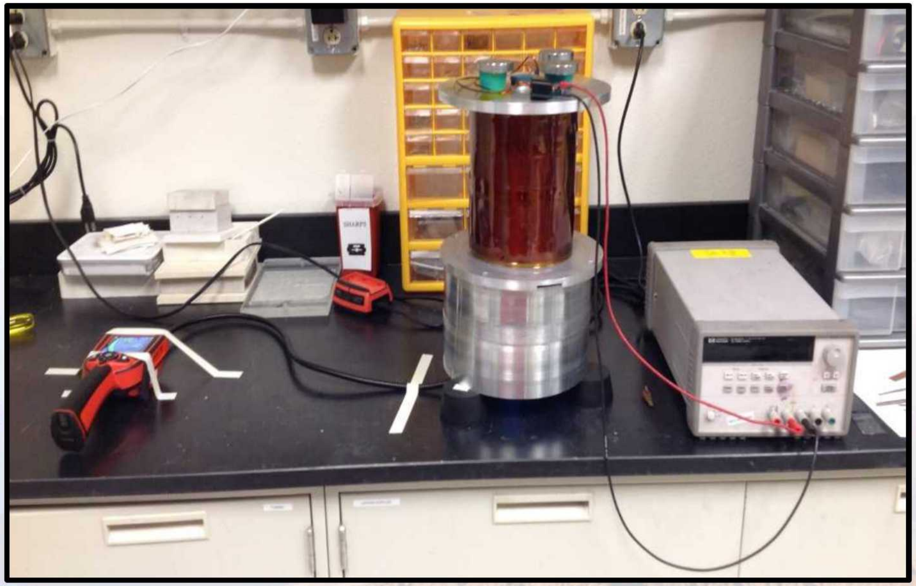


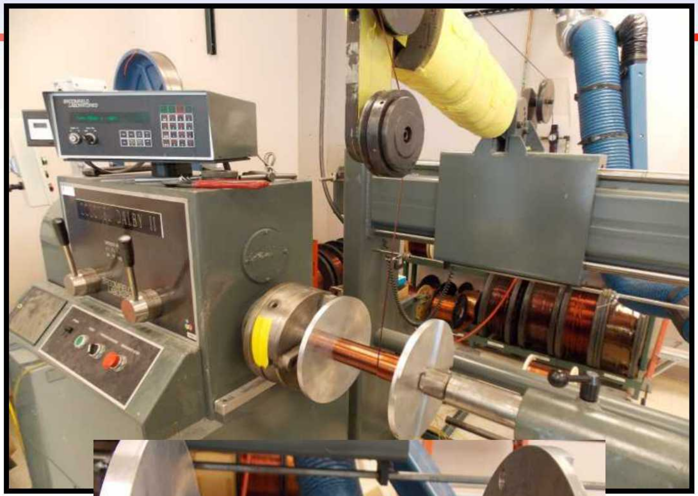
Bubbler with N_2 gas

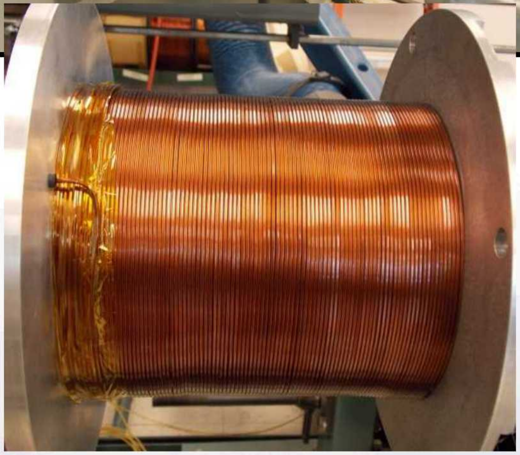
- Initial deposited films were highly oxidized and powdery rather than metallic
- Oxidation of Fe^{2+} needs to be inhibited
  - 2 types of oxygen scavengers used
- Other Additives: grain refiner and a surfactant

Solenoid Development and Testing Setup

- To test the magnetostriction of electrodeposited films, a solenoid was modeled, built, and calibrated
- Fabrication performed by Sandians in the Electronic Fabrication Dept., Org. 02663



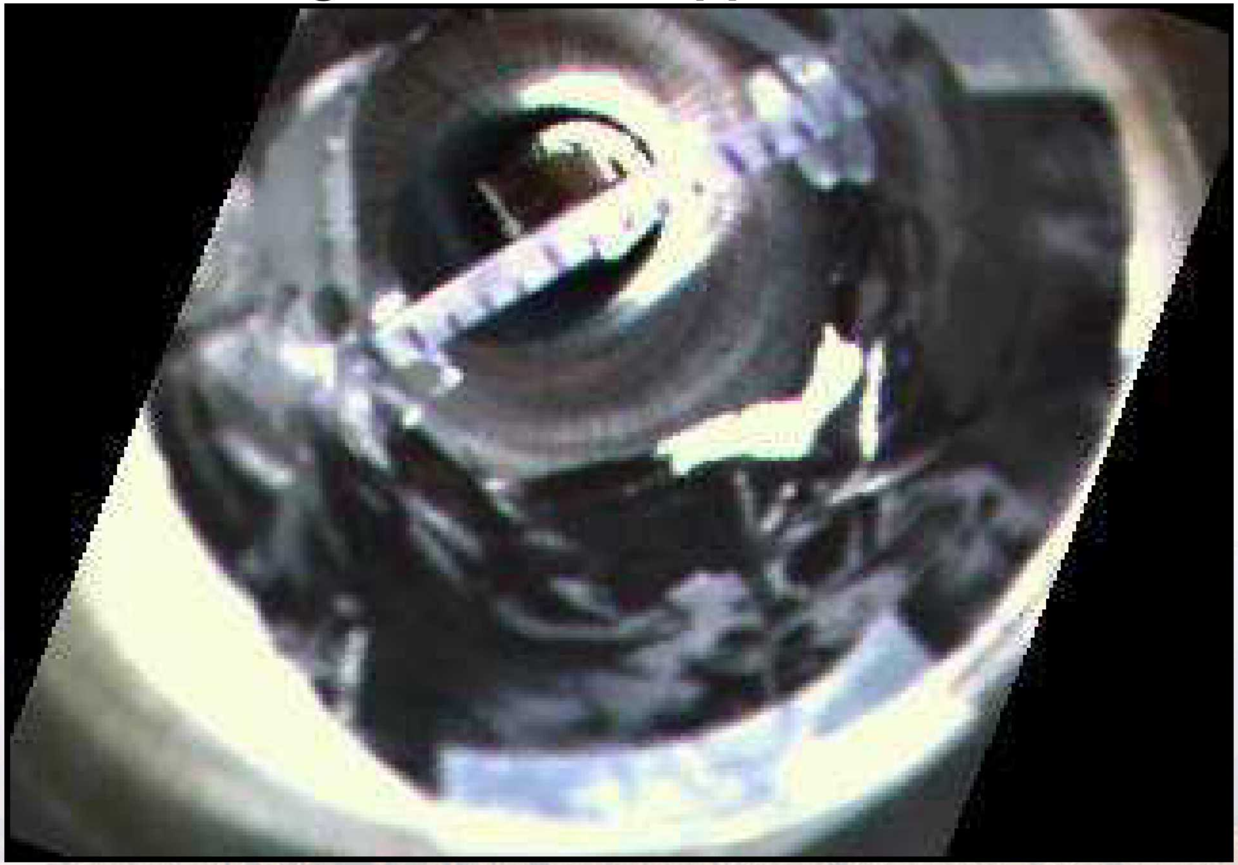




- Completed solenoid setup with power supply and Ridgid inspection camera to view and measure samples *in situ*

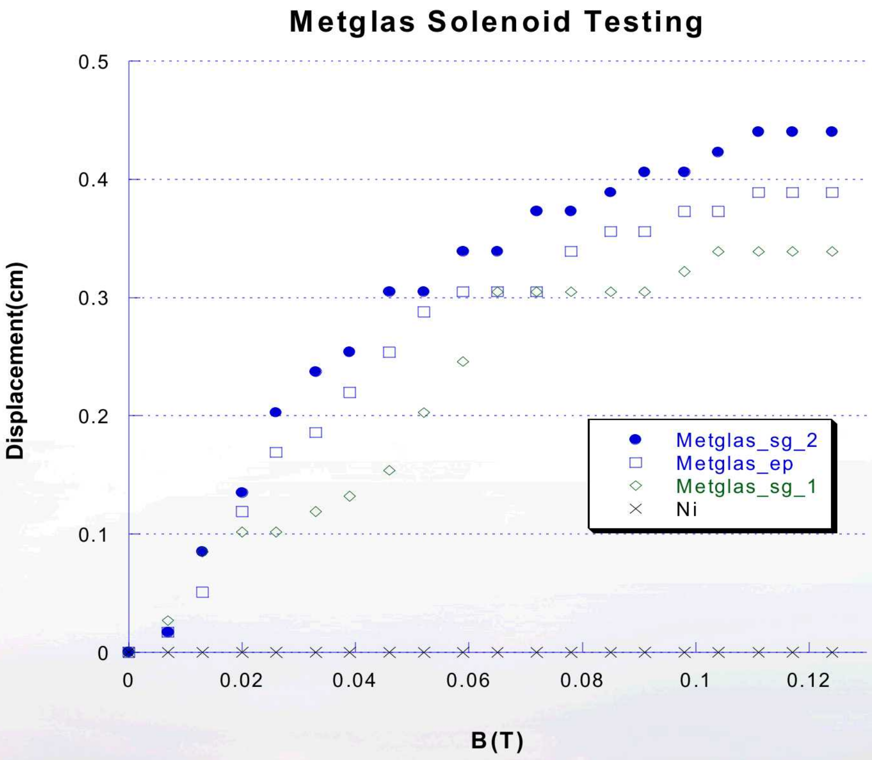
Magnetic Testing

- **Ridgid inspection camera view showing sample P1 before a magnetic field is applied and with 0.124T field**



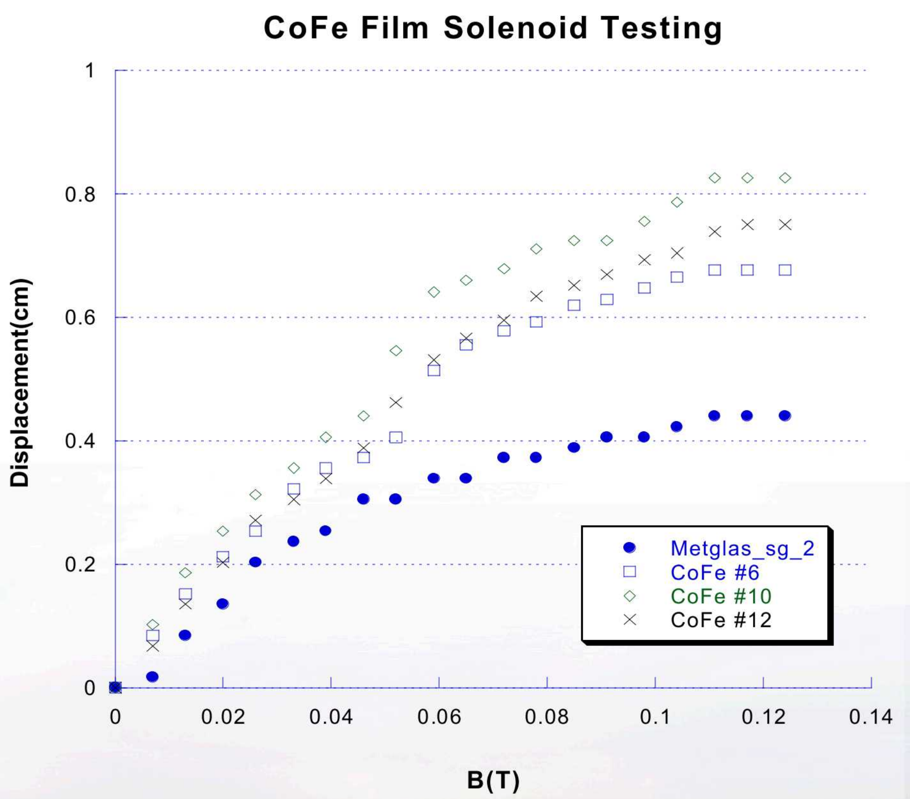
Baseline Magnetic Testing

- **METGLAS® 2605 SA1 samples, with a known magnetostriction of λ=27ppm, used as a baseline for magnetic field testing**
  - With a standard deviation of ±0.044cm, all sample tests are within range
- **A control sample electrodeposited from nickel sulfamate chemistry was tested and showed no displacement up to an applied magnetic field of 0.124T**
  - This verifies that effect seen is magnetostriction

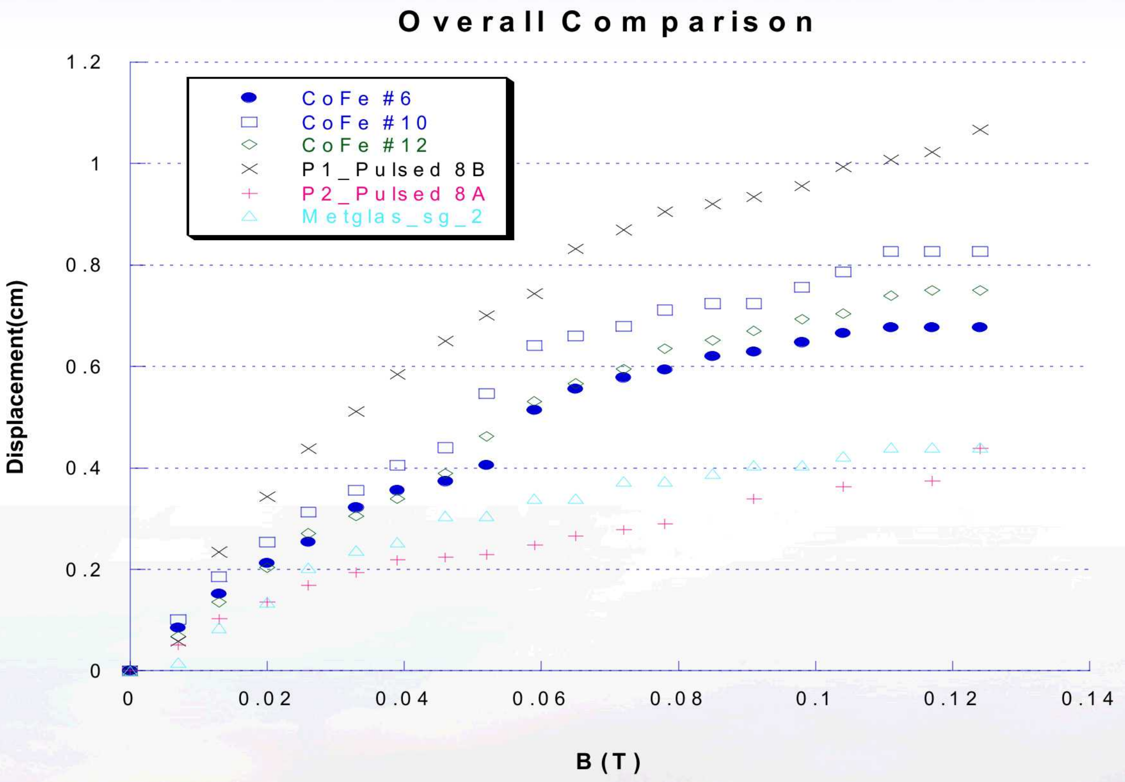


Magnetic Testing

- **CoFe samples with EDS results showing the ideal stoichiometric range of approximately 70:30 Co to Fe**
- **Chemistry (8B) showed better displacement from magnetostriction and top 3 samples are graphed**
- **Best sample shows almost twice the displacement as the best tested Metglas sample**

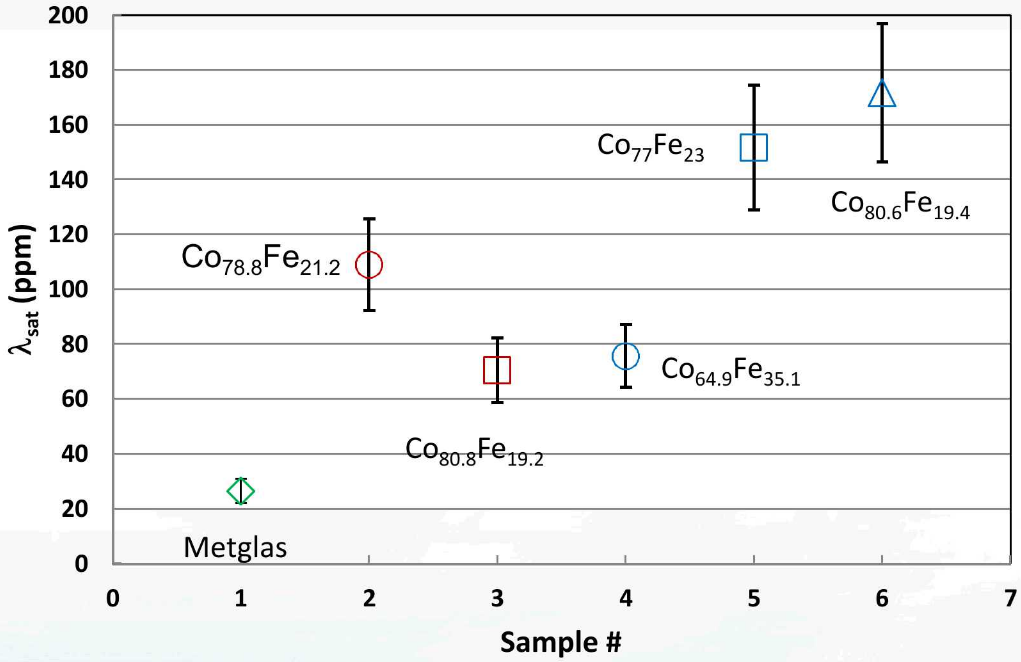


Magnetic Testing



- Pulsed sample using 8B chemistry shows the best displacement measurement

λ_{sat} Comparison



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

Expression du Tremolet de Lacheisserie and Peuzin

- METGLAS® 2605 SA1 sample measured at 26±4 ppm within range of manufacturer's specified λ_{sat} of 27 ppm.
- Highest recorded λ_{sat} for electrodeposited films measured at 172 ±25 ppm. This value of λ_{sat} is greater than as-deposited sputtered films of 84±5 ppm achieved by Hunter *et al*

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