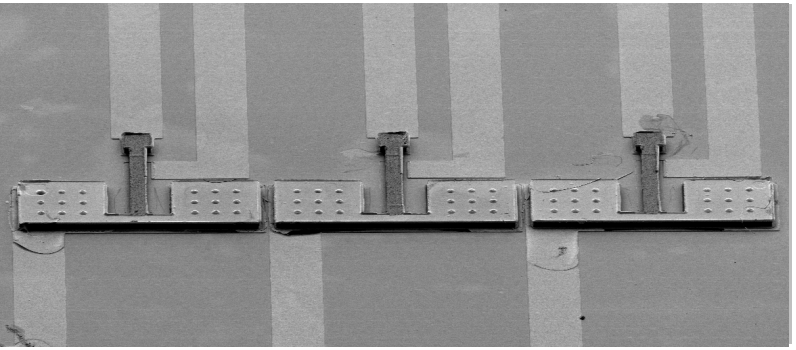
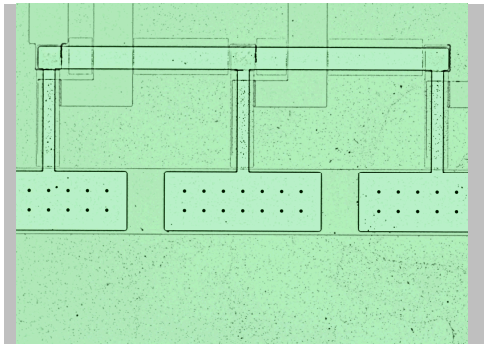
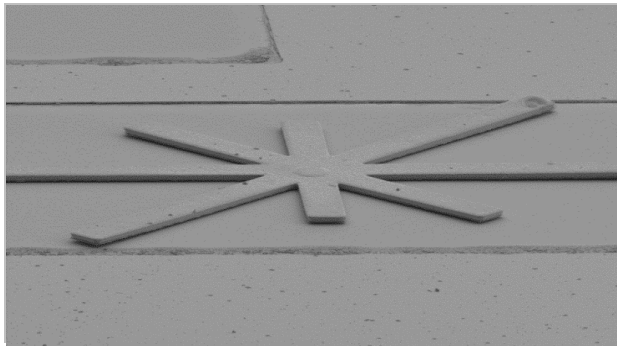
SAND2017-3570C

Process Integration of Electroformed MEMS Variable Capacitors

for magnetostriction measurements

Patrick S. Finnegan, Eric Langlois, Christian L. Arrington, Andrew E. Hollowell, Jamin R. Pillars, Todd Monson, and Christopher St John

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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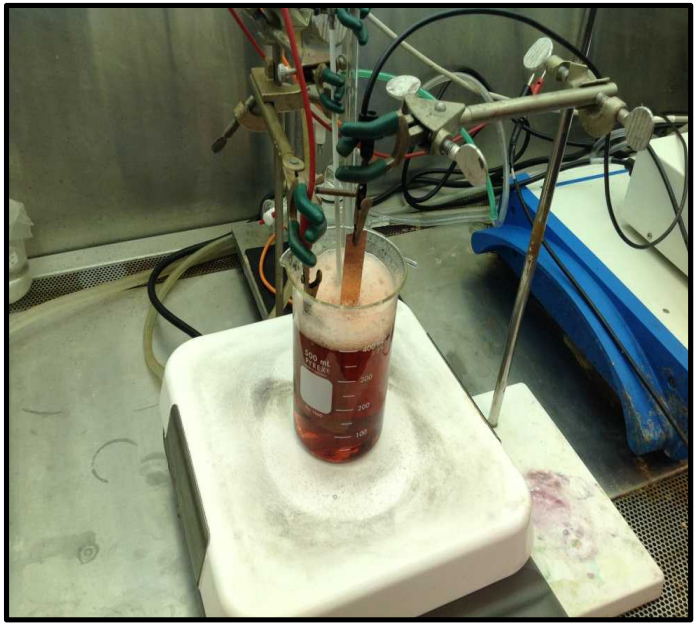
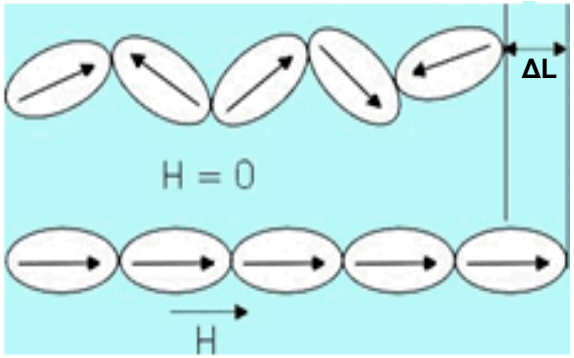
Electrodeposited CoFe Films

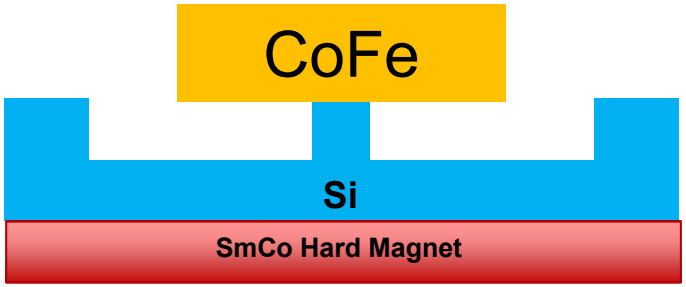


Advantages of Electrochemically Deposited CoFe	
1.	In situ patterning via photoresist mold process
2.	Arrays of multi-frequency magnetic resonators
3.	Large thickness range (1μm to 1mm)
4.	Low intrinsic stress
5.	Higher degree of magnetostriction than Metglas (48 ppm to 78 ppm as measured by Naval Research Labs) possible without high temperature annealing

Magnetostriction

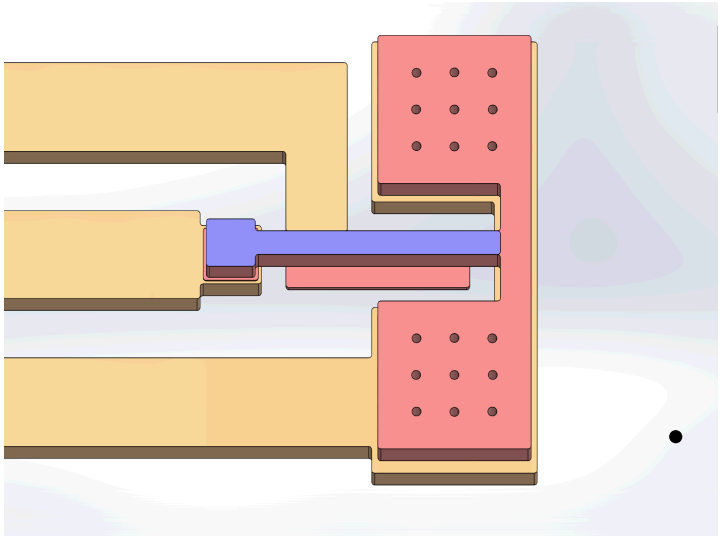


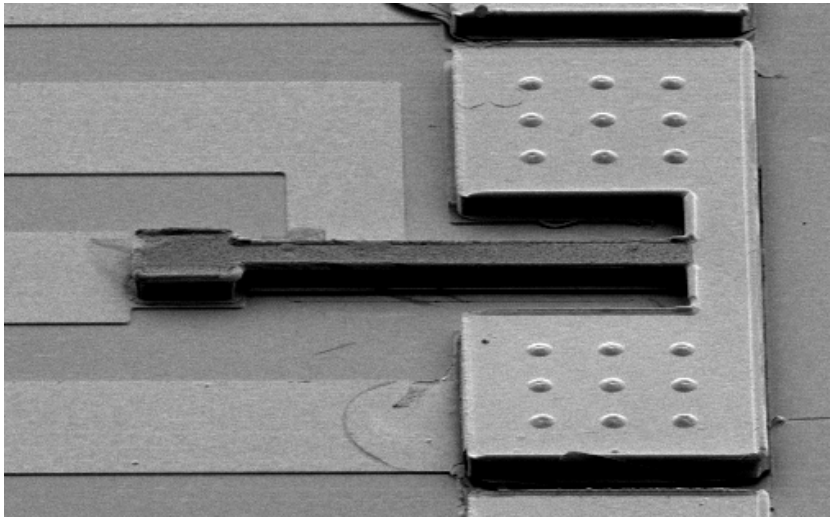
The fractional change in length as the magnetization of a material increases from zero to saturation.

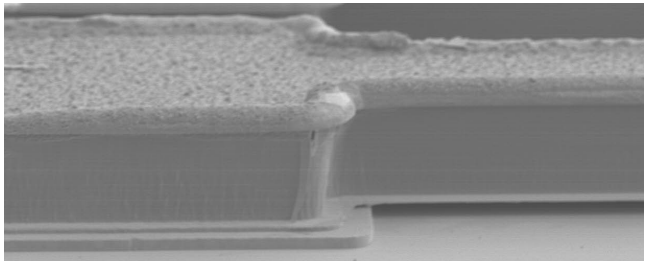


CoFe resonator x-section

Variable Capacitor Device Design

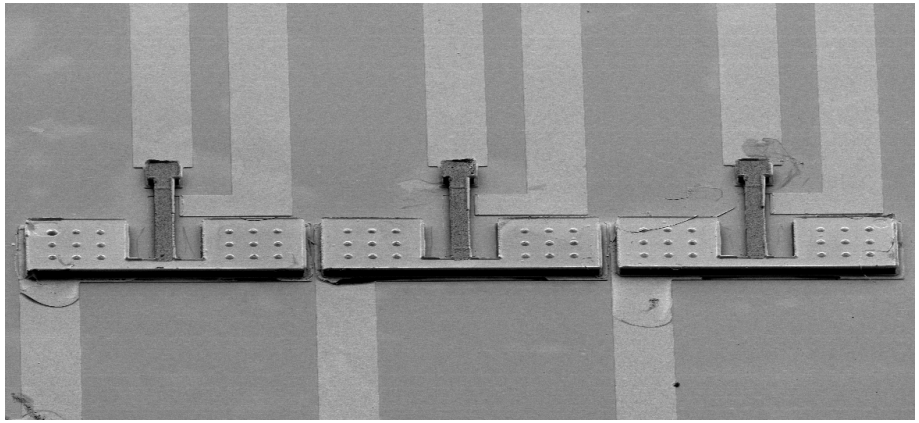




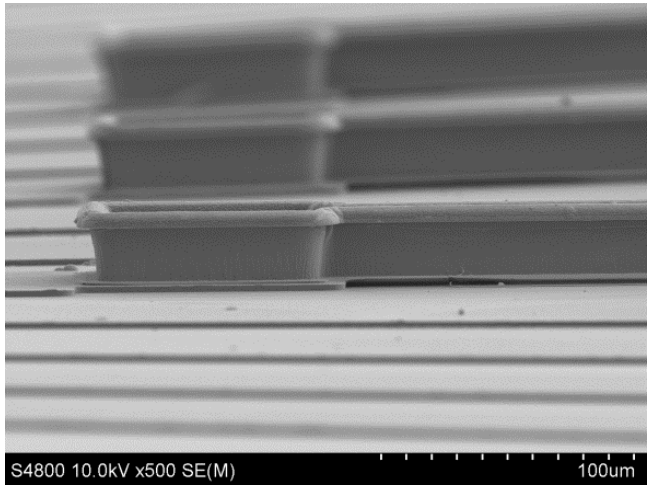


- Metal 1 Electrostatic actuator (0.5μm)
- Metal 2 Electrode circuitry for top and bottom plates of capacitor (3μm)
- Metal 3 Capacitor post 1(μm)
- Metal 4 Mechanical cantilever (20μm)
- Metal 5 CoFe alloy (0.35μm)

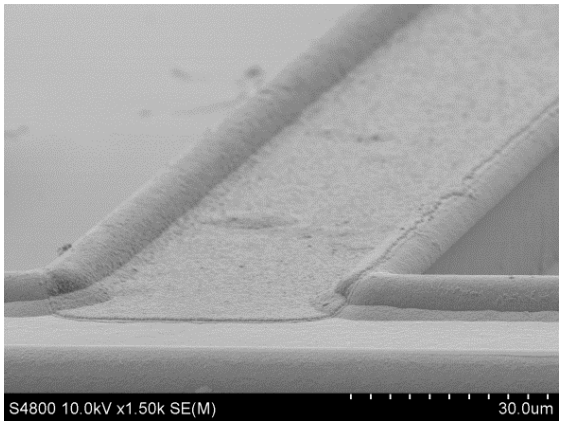
Capacitor Function



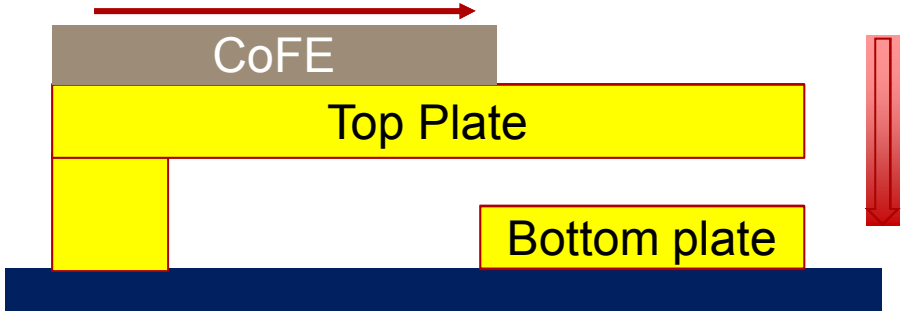
Planar cantilever structures released



Cantilever profile



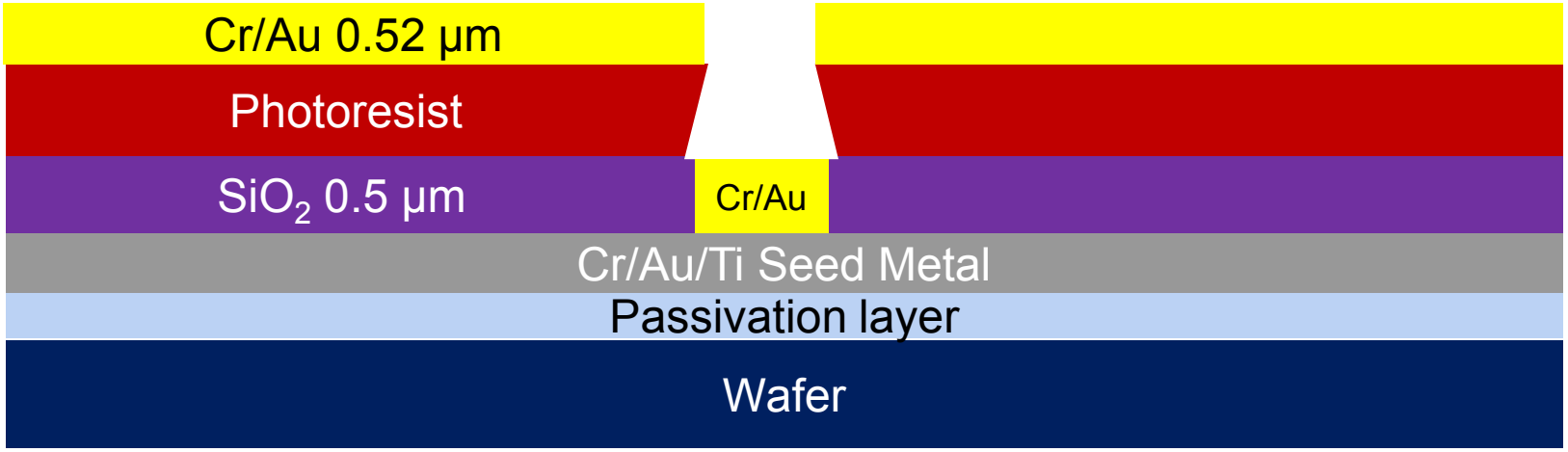
CoFe Alloy atop Au cantilever



Magnetic Field

Metal One Planar Liftoff

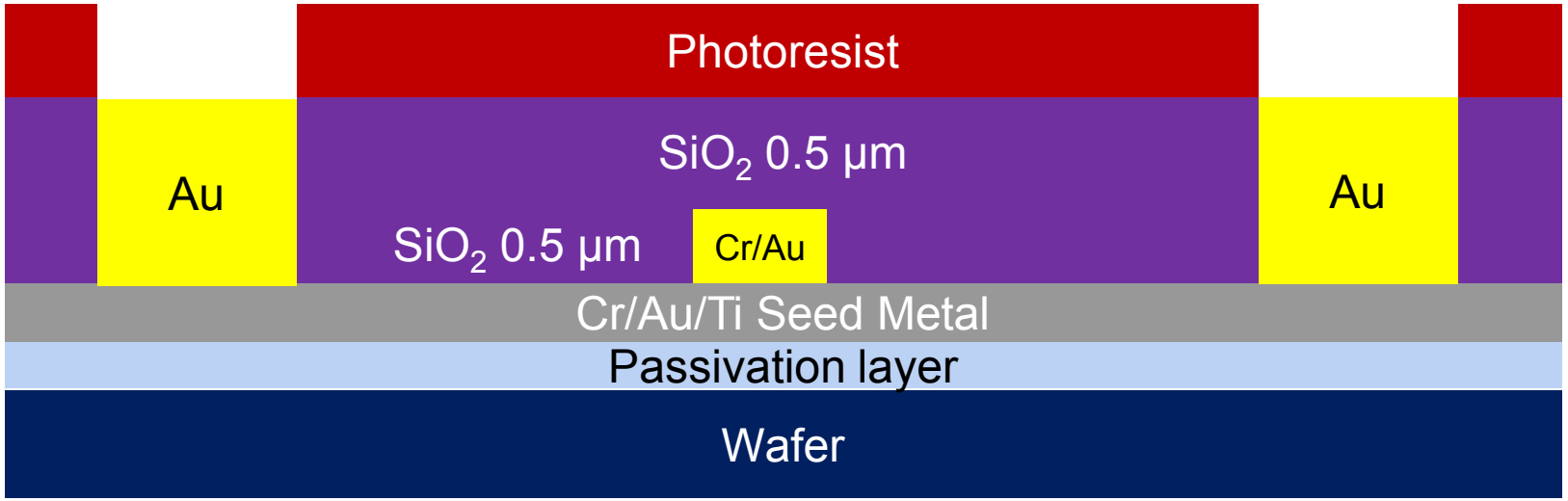
- Deposit a passivation layer
- Seed metal evaporation Cr/Au 200/1000Å
- Deposit 0.5µm CVD SiO_2
- Spin coat/expose and develop photoresist
- RIE Etch SiO_2
- Evaporative metal deposition Cr/Au 200/5000Å
- Metal liftoff in solvents



Metal 2 Electrochemical Deposition

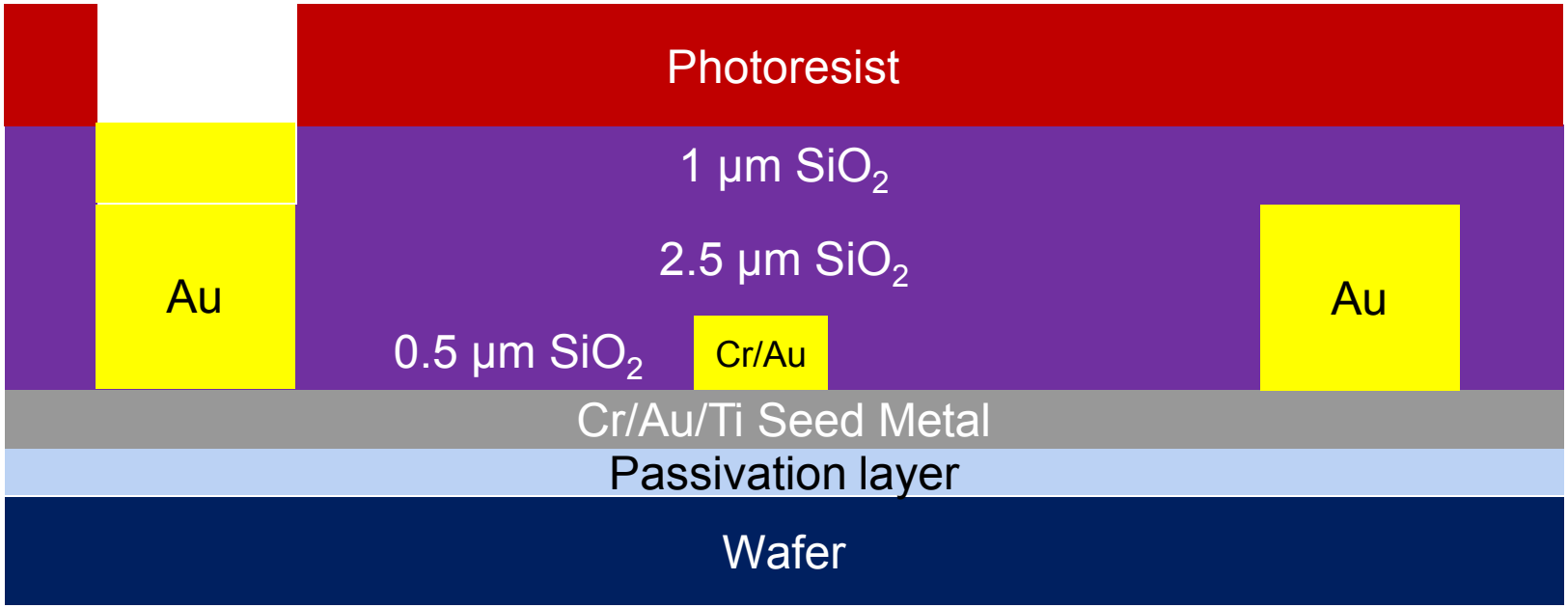
Sandia National Laboratories

- Deposit 2.5 μm CVD SiO_2
- Spin coat/expose and develop photoresist
- RIE Etch SiO_2
- Remove photoresist
- Electroplate 3 μm Au



Metal 3 Electrochemical Deposition

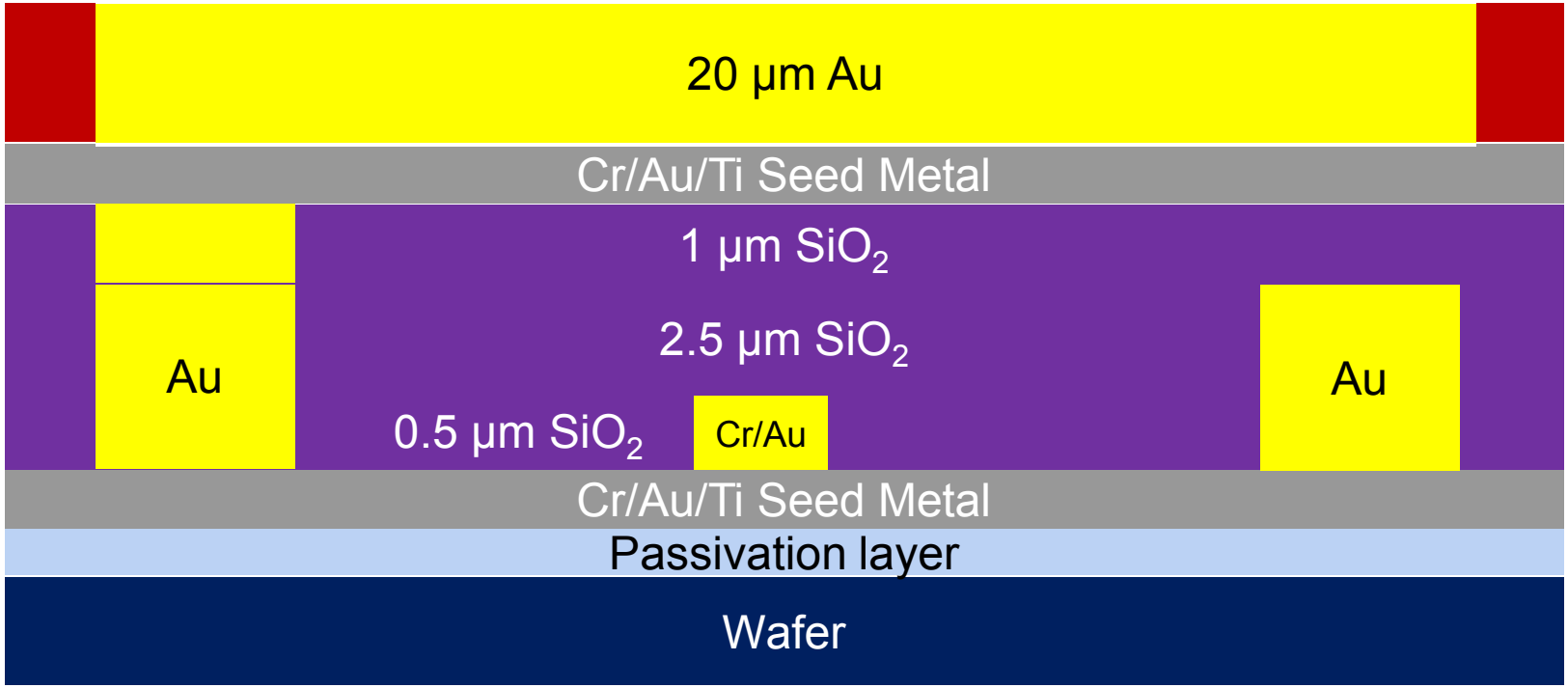
- Deposit 1 μm CVD SiO_2
- Spin Coat/Expose and develop photoresist
- RIE Etch SiO_2
- Remove Photoresist
- Electroplate 1 μm Au



Metal 4 Electrochemical Deposition

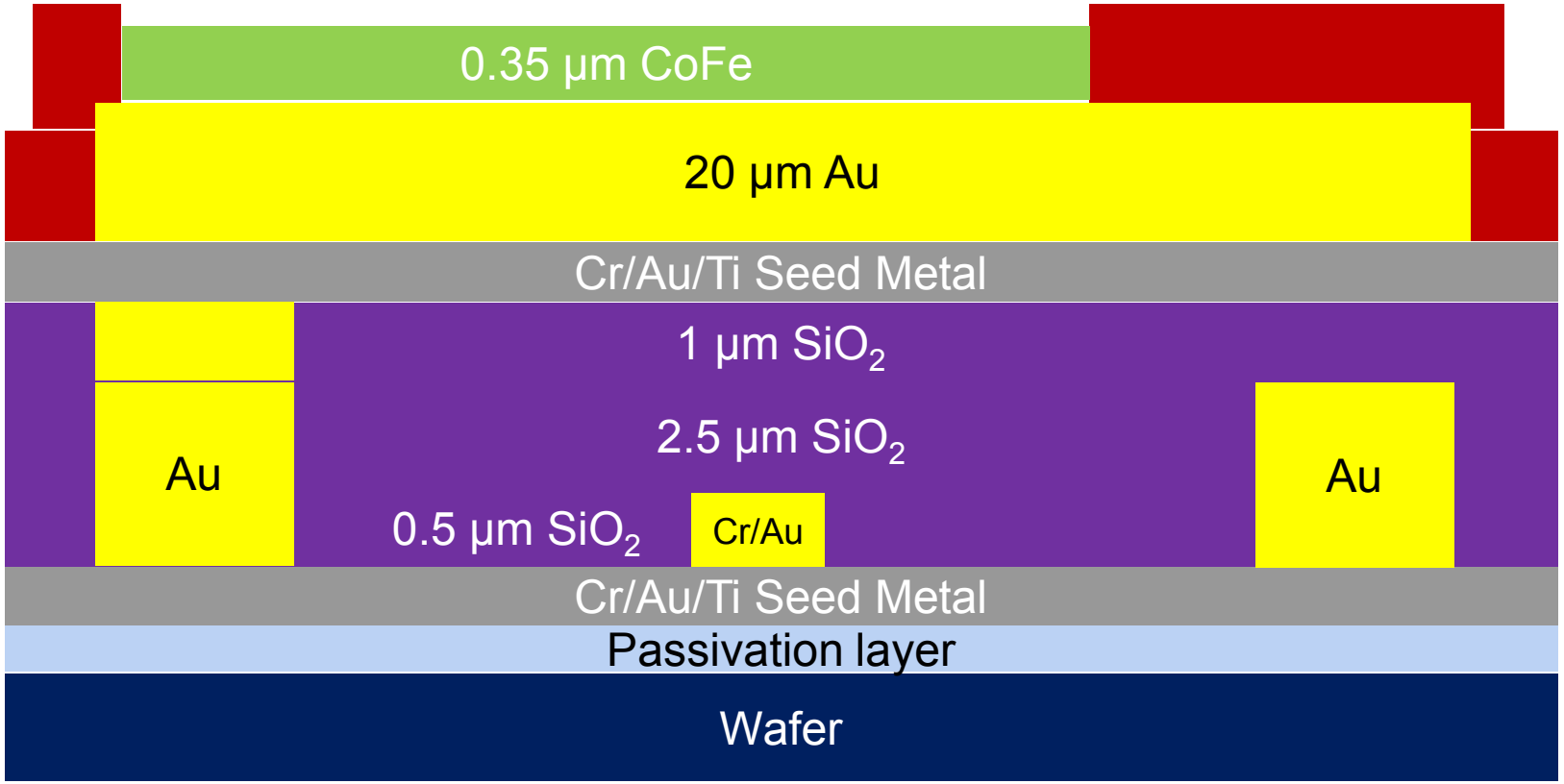
Sandia National Laboratories

- Seed metal evaporation Cr/Au 200/1000Å
- Spin Coat/expose and develop 20 µm photoresist
- Electroplate 20 µm Au
- Remove Photoresist



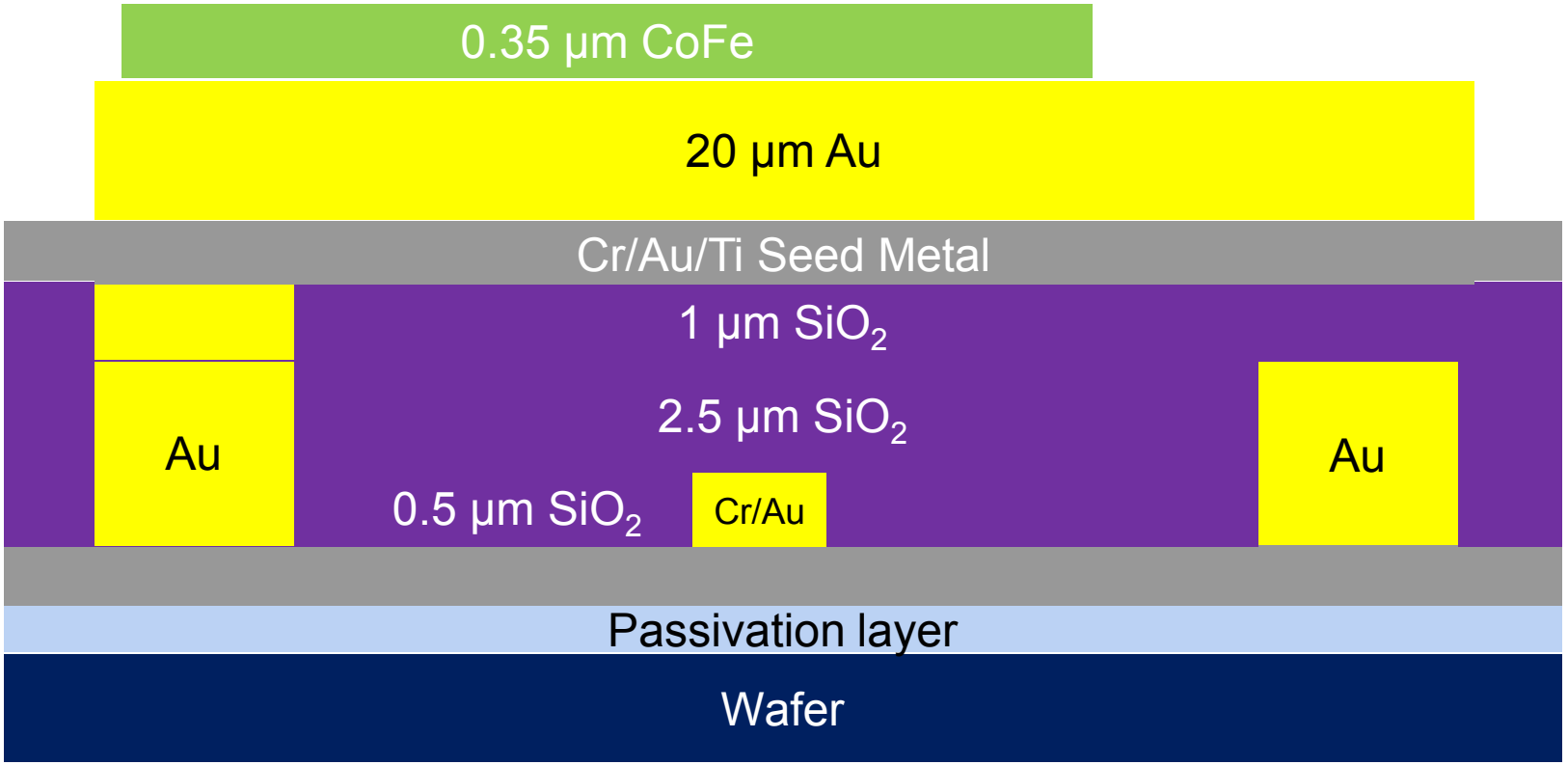
Metal 5 Electrochemical Deposition

- Spin Coat/expose and develop photoresist
- Electroplate 3500Å CoFe
- Remove Photoresist



Device Release

- Top Seed Metal Removal in Ar Ion Mill
- Sacrificial SiO_2 etch release in Hydrofluoric Acid
- Bottom Seed Metal Removal in Ar Ion Mill

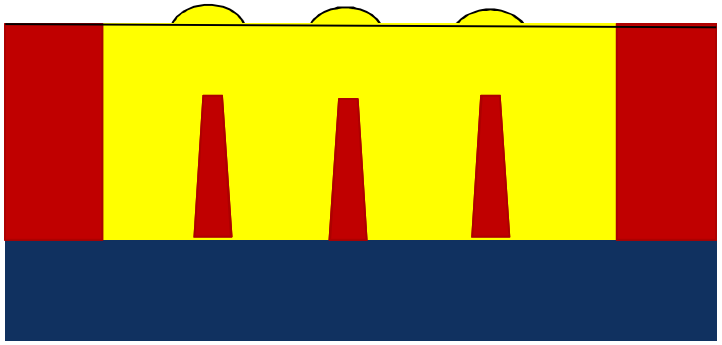


Accomplishments

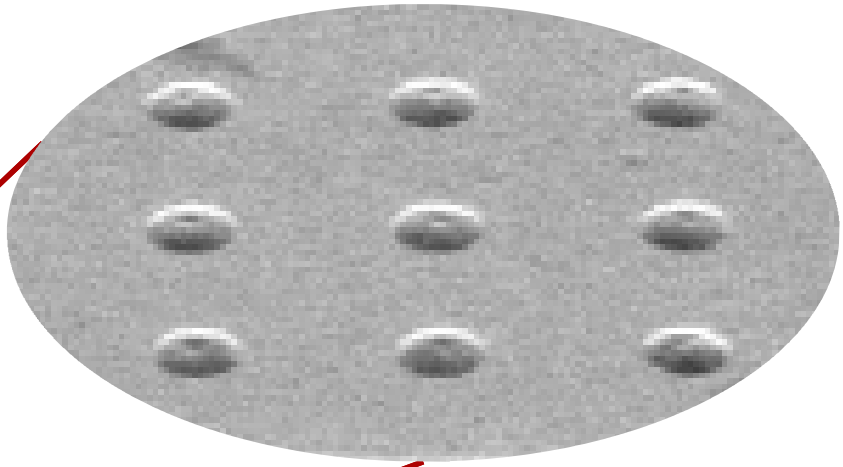
Sandia National Laboratories

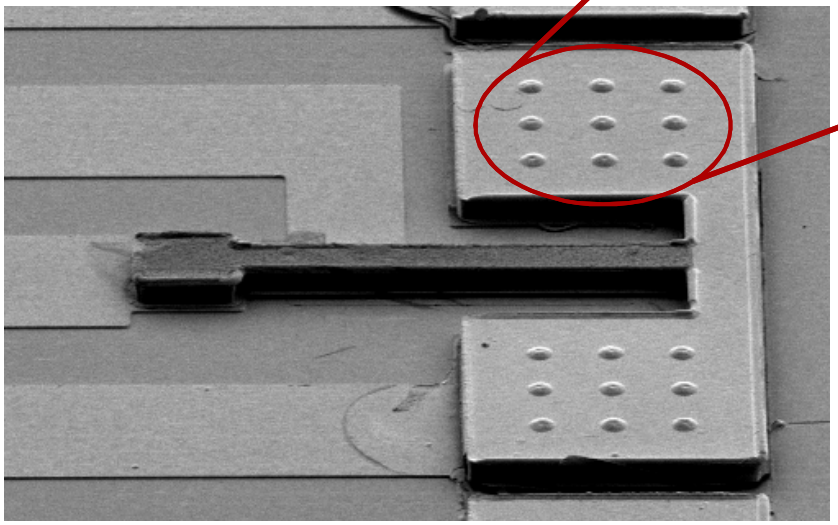
- Developed an electrochemical deposition of CoFE
- Patterned electroplated CoFe using photoresist plating molds
- Developed a prototype MEMS capacitor process with an integrated CoFe

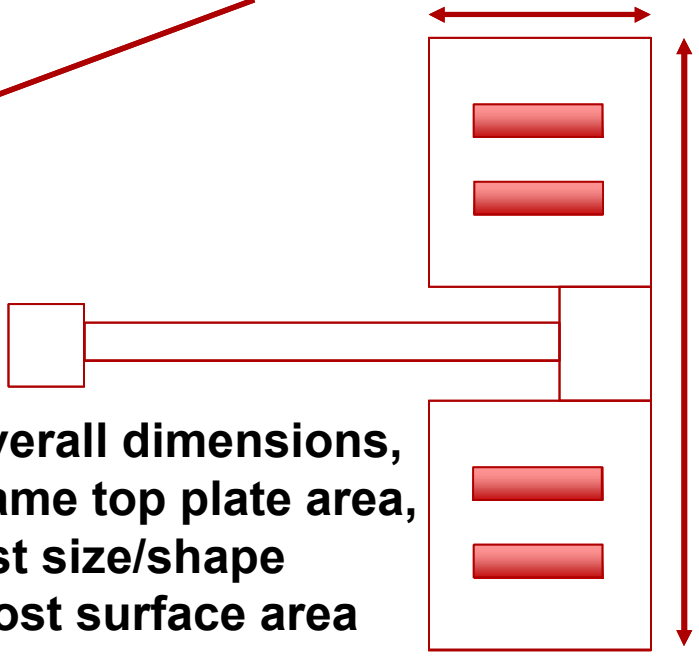
Lesson Learned



Cross Section: Resist mold for M4. Release hole posts erode

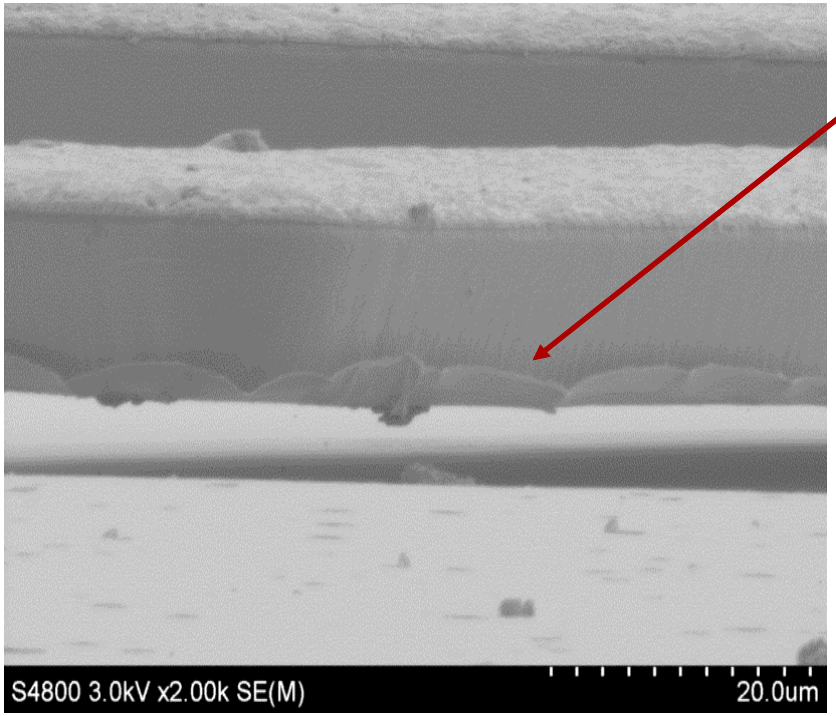




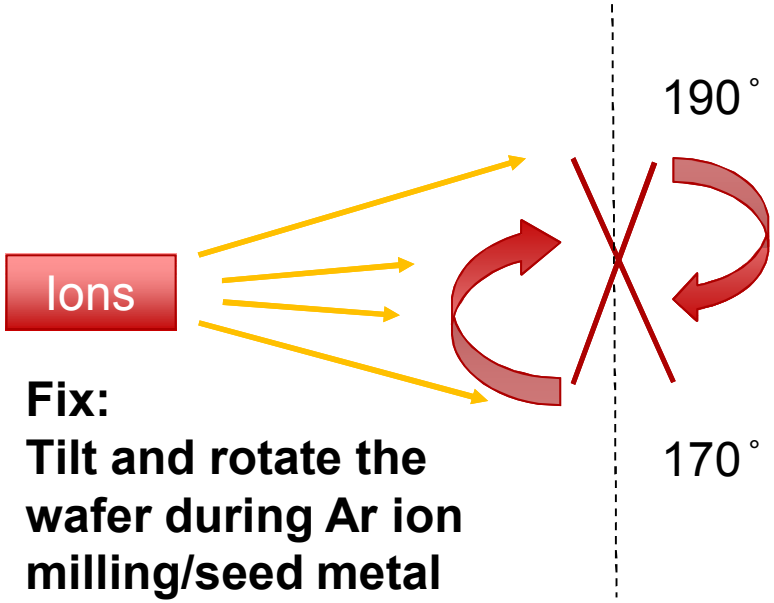


Fix:
Increase overall dimensions, maintain same top plate area, change post size/shape reducing post surface area

Lesson Learned



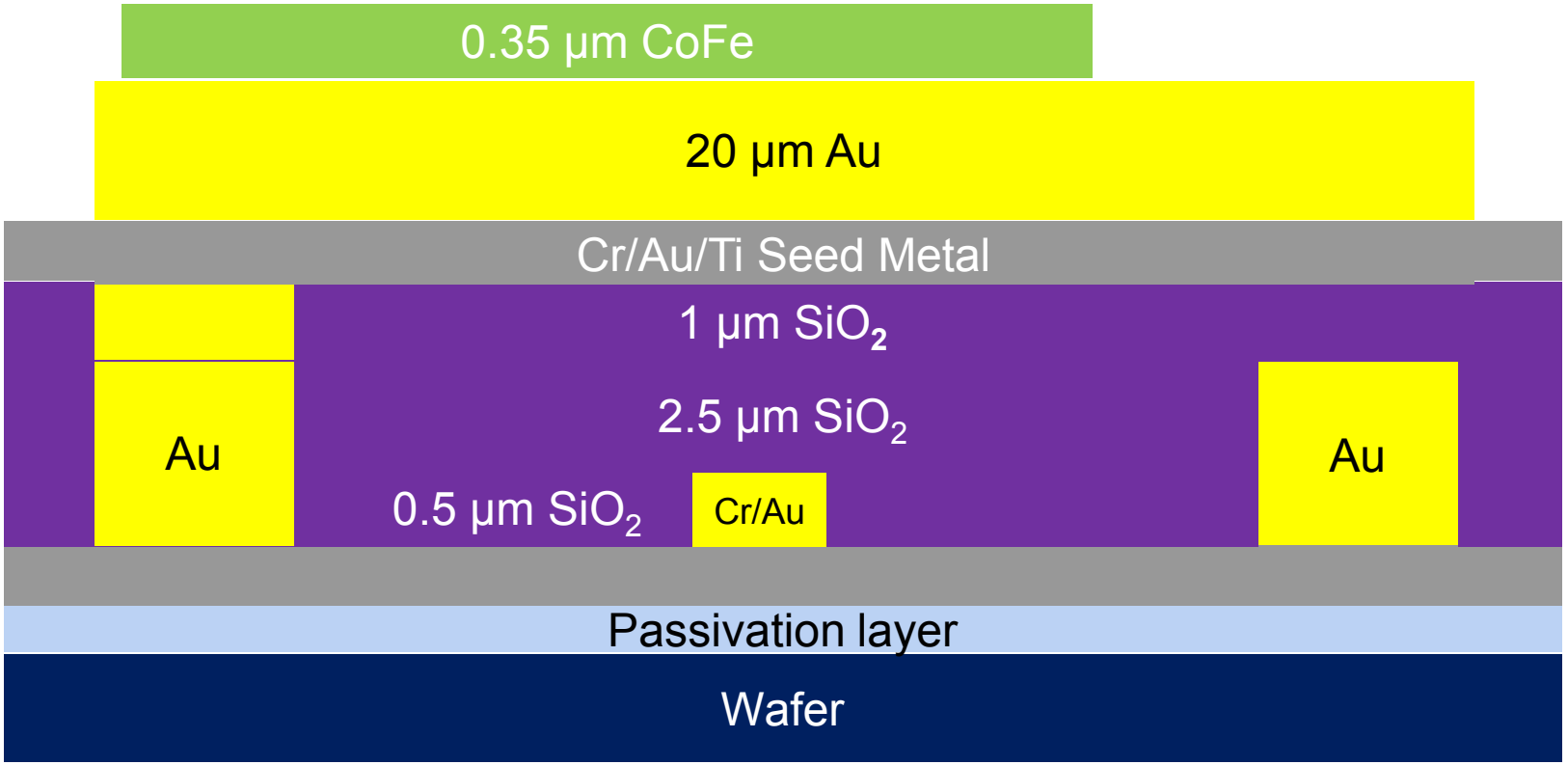
Seed metal flap on underside of cantilever structures Caused by directional line of sight Ar ion milling



Fix:
Tilt and rotate the wafer during Ar ion milling/seed metal removal

Future work

- Replace M3 sacrificial SiO_2 with a photoresist to facilitate release and prevent delamination issues



Acknowledgments

- 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, “Magnetic Smart Tags (MaST) for Arms Control and Treaty Verification.“ and Workstream 3 Delivery for JTD

- Adam Thorpe and Loren Gastian of Sandia National Laboratories Albuquerque for outstanding technical support.

Sandia National Laboratories

Questions?

Related ECS talks

Sandia National Laboratories

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

Tuesday, 4 October 2016: 10:20, 320A (Hawaii Convention Center)

"Magnetolastic Smart Tags Using Electroformed Cobalt Iron Boron"

Tuesday, 4 October 2016: 10:40, 302A (Hawaii Convention Center)

"Optimized CoFeB Alloy Films for Electroformed Resonators" on Friday, 7 October 2016: 11:40, 305 A (Hawaii Convention Center)

SiO_2 & Dry etch Chemistry

- SiO2 RIE Etch

  45sccm CHF3, 50W, pressure 10mT, 25° C (2.89A/second)

- Ion Mill

  accel voltage= 400W, Beam current= 300mA, beam voltage 500V, Ar chamber 5sccm, Ar gun 5sccm ethch angle 1= 170° ,angle 2= 190° , 2 etch segments of 150seconds

- Ti removal RIE

  14sccm SF6, 5sccm Ar, 20mT, 100W, 3min

Electroplating Chemistries

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 (Hawaii Convention Center)