SAND2022-13749C

Sandia National Laboratories

Morphology and Electrochemistry Drive Corrosion of Electroless Nickel Immersion Gold Films: A Multi-Technique Analysis

PRESENTED BY

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Team –

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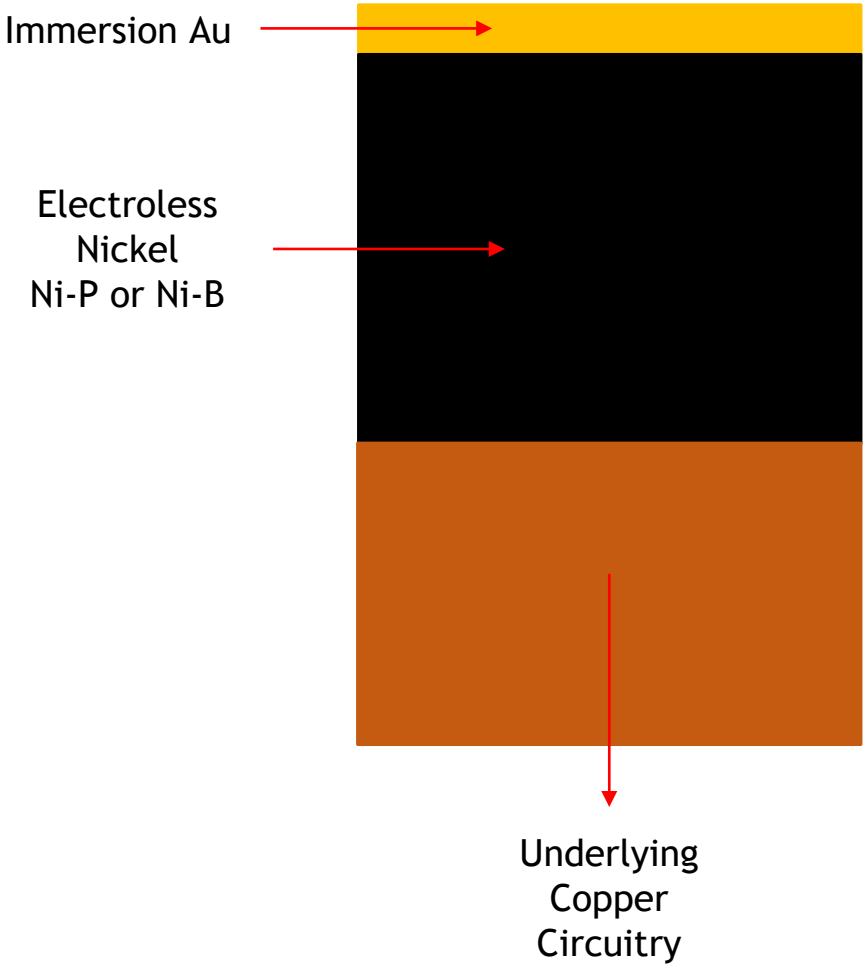
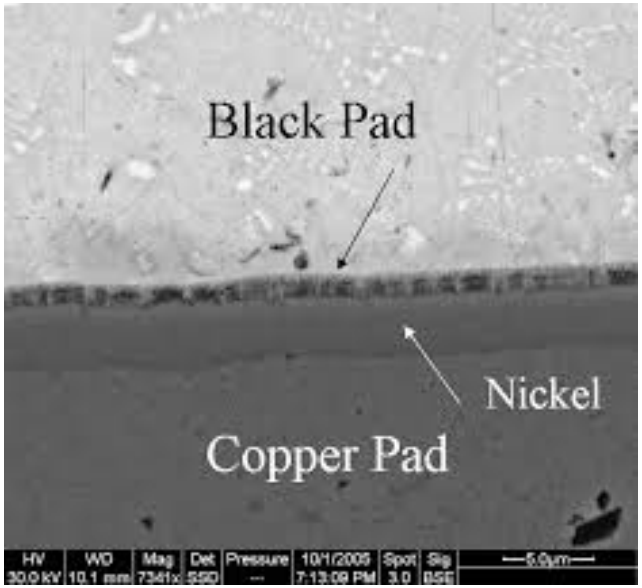
U.S. DEPARTMENT OF ENERGY NNSA

Electroless Nickel Immersion Gold (ENIG)



Enhance solderability to copper pads

Minimize oxidation of base Cu layer



Pecht et al 2008
doi:10.1016/j.microrel.2008.02.003

<u>"Black Pad" phenomenology not well explained in literature</u>

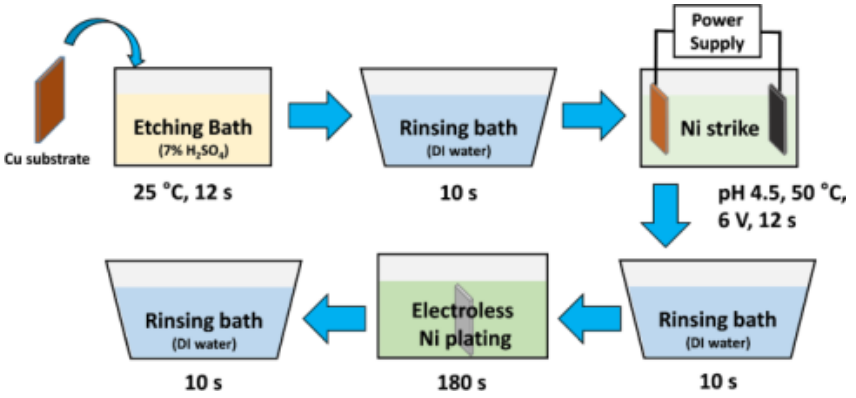
ENIG Plating Simplified

$$NiSO_4 + NiH_2PO_2 + H_2O \xrightarrow{Heat,Catalyst} Ni + NaH_2PO_3 + H_2SO_4$$

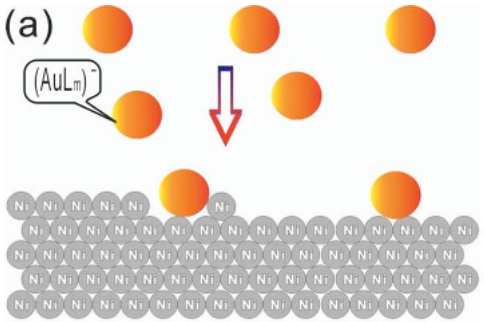
1) Electroless Nickel

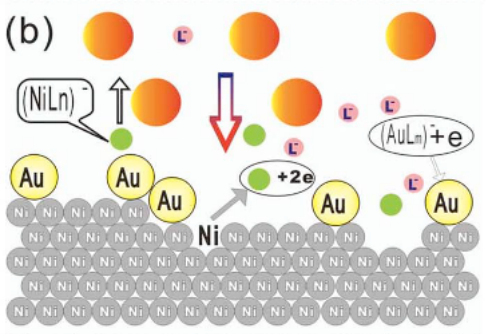
Process Inputs

Metal salt concentration
Additive 1 concentration
Additive 2 concentration
pH
Temperature
Current density
Agitation



2) Immersion Gold

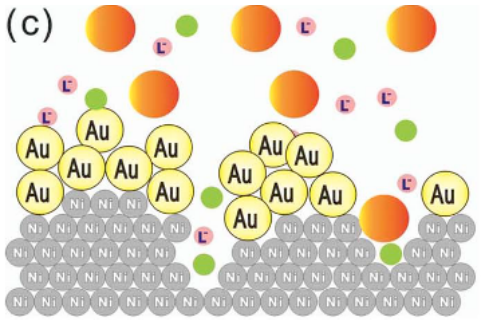




Anodic Reaction:
$Ni \rightarrow Ni^{2+} + 2e^-$
$E_{Ni^{2+}/Ni} = -0.275\ V$ vs SHE

Cathodic Reaction:
$Au^+ + e^- \rightarrow Au^0$
$E_{Au^+/Au} = 1.692\ V$ vs SHE

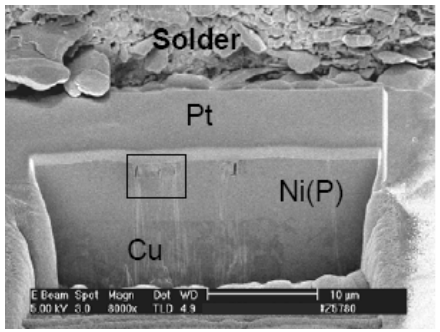
Overall Reaction:
$Ni + 2Au^+ \rightarrow Ni^{2+} + 2Au^0$

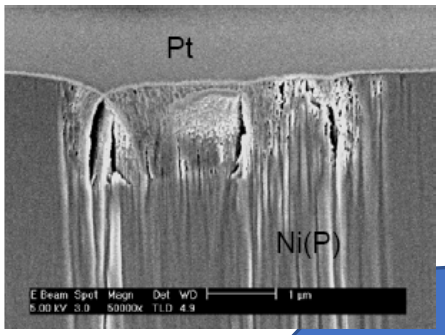


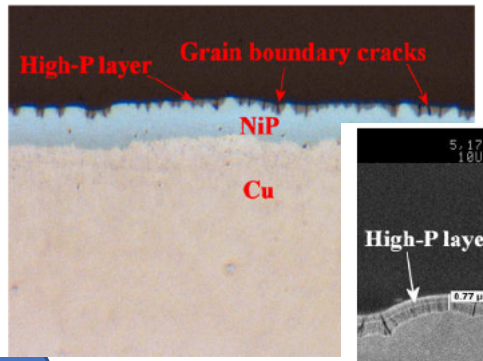
Liu *et al* 2007
https://doi.org/10.1149/1.2790281

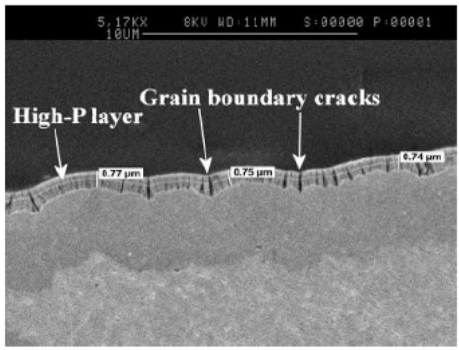
Let's Agree to Disagree on the Root Cause(s)

Too Much (or Too Little) Phos.





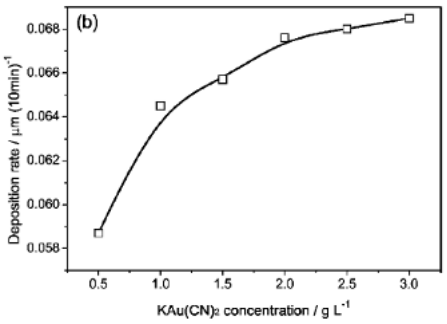


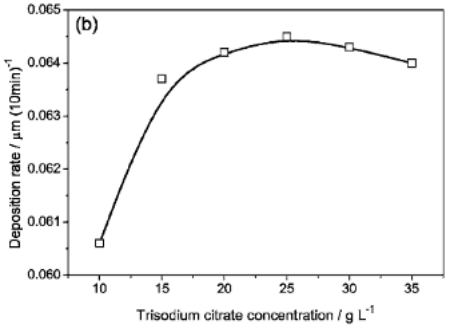


Galvanic Hyper-Corrosion of Ni(P)

Zeng *et al* 2006
https://doi.org/10.1109/ITHERM.2006.1645469

Potential Root Causes

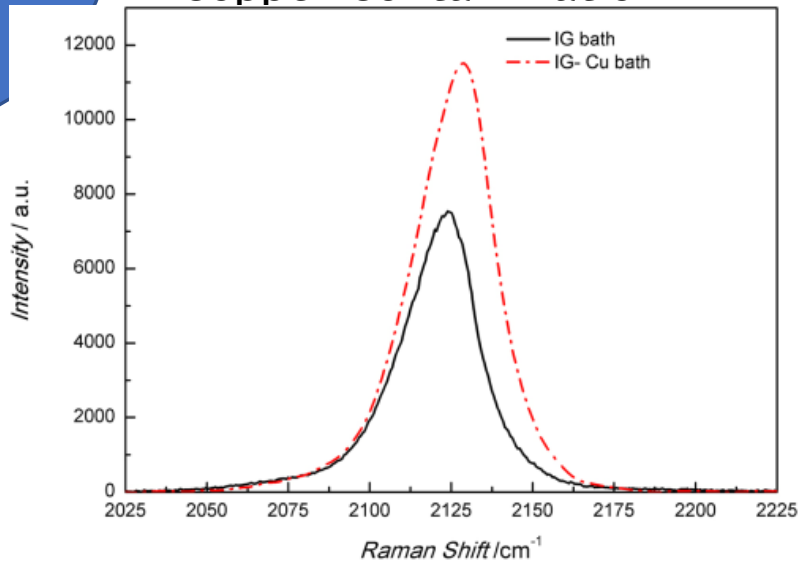




Additives and Complexing Agents

Liu *et al* 2007
https://doi.org/10.1149/1.2790281

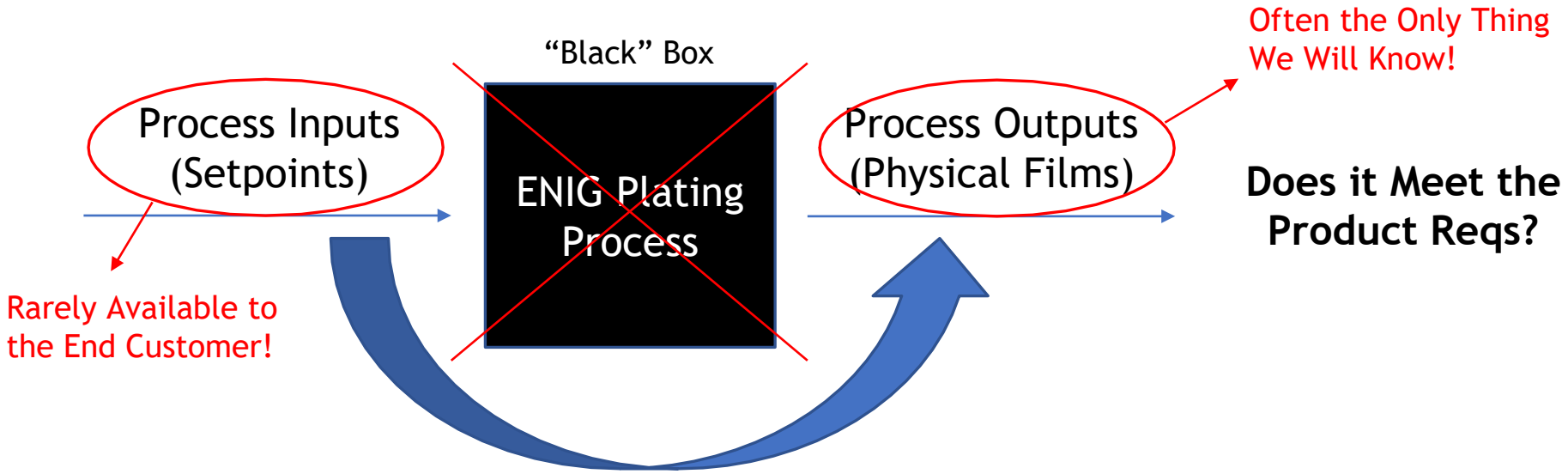
Copper Contamination



Accogli et. al 2022
https://doi.org/10.1149/1945-7111/ab8ce6

An Alternative Perspective

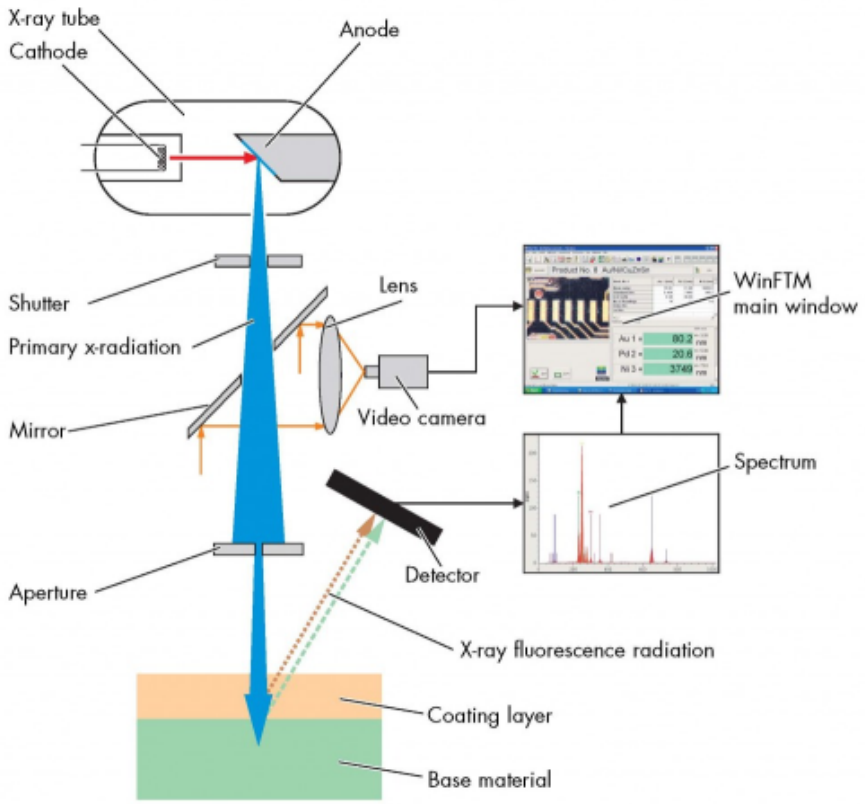
In-Situ Diagnosis of the Root Cause of Poor ENIG Plating is a High-Complexity, Low Reward Effort



Can We Develop Methodologies to Distinguish Amongst These Potential Failure Modes Without the Luxury of Peeking Into the Black Box?

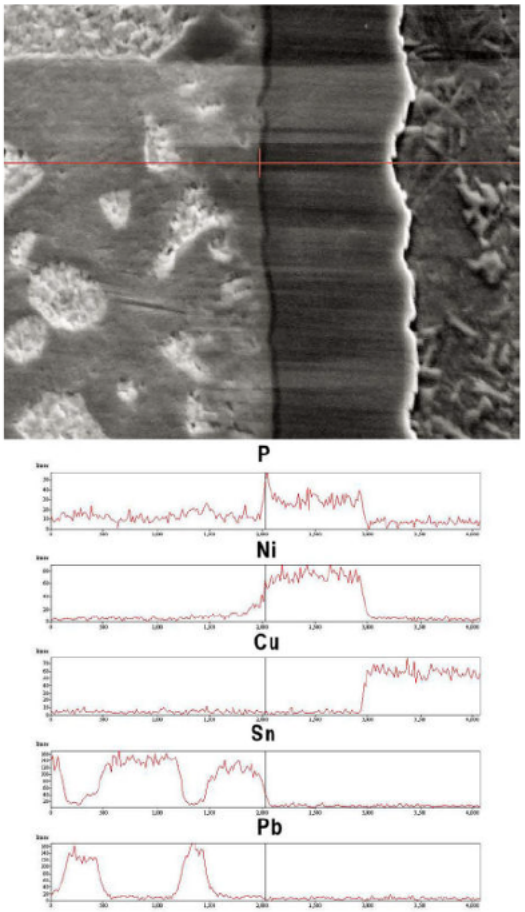
How is ENIG (Post)Characterized Now?

X-Ray Fluorescence (XRF) Spectroscopy



Chemical speciation, some structural information

FIB Section and SEM/EDS

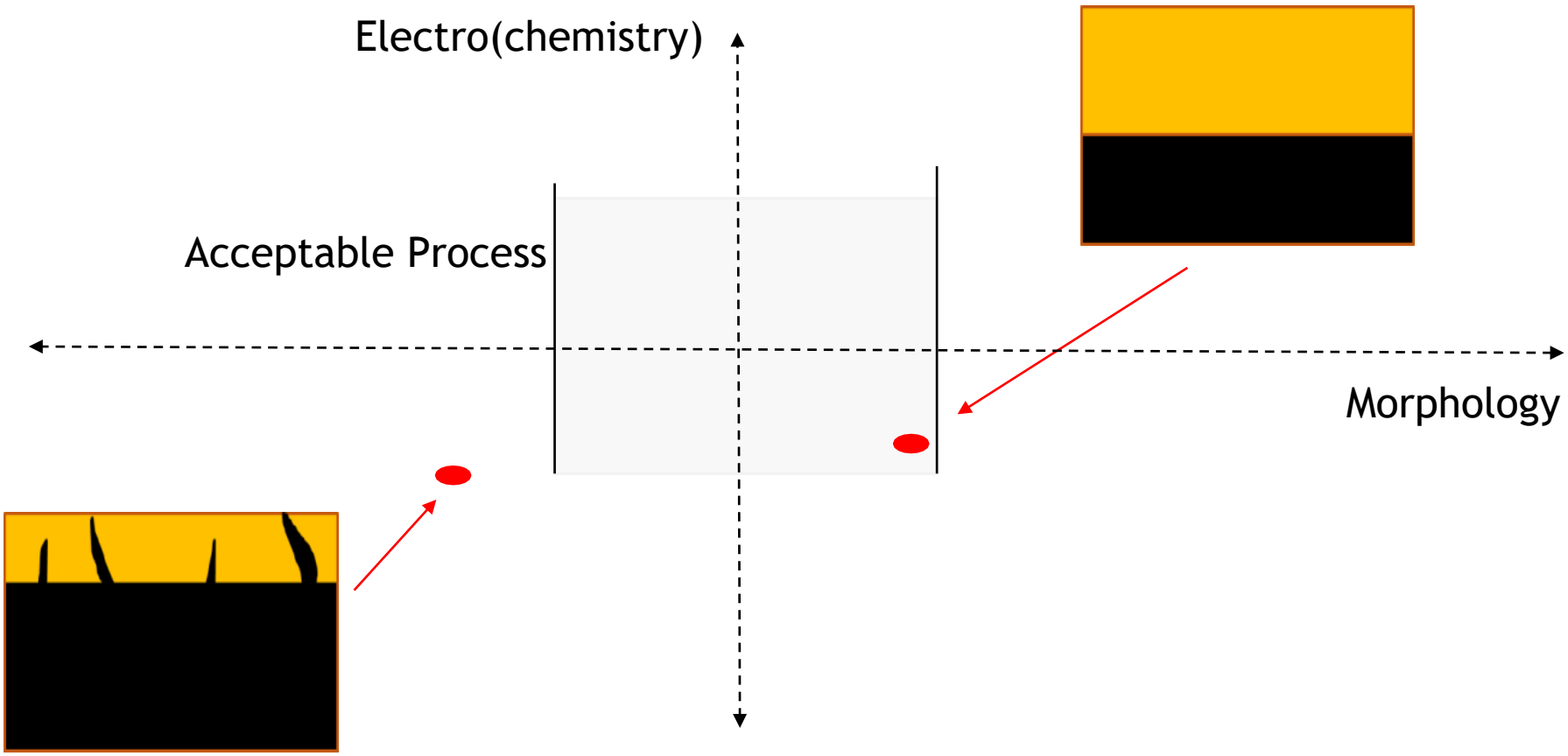


Low-quality chemical speciation, high-quality structural information

Electrochemical Information?

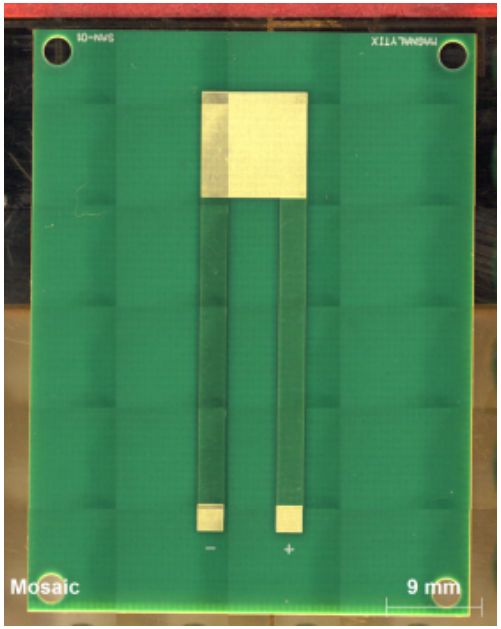
Hypothesis

Electro(chemistry) and Morphology Dictate Whether ENIG Films Meet Performance Requirements



Insights Into **Both** the **Electro(chemistry) and Morphology** of an ENIG Film Are Necessary to Properly Classify Whether Process -> Performance

Experimental Design & Methodology



Electro(chemistry)

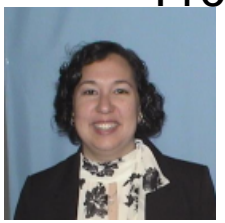
Cyclic Polarization

SVET

Preet Singh
Georgia Tech.

XPS Depth Profiling

Samantha Rosenberg
Sandia Nat'l Labs



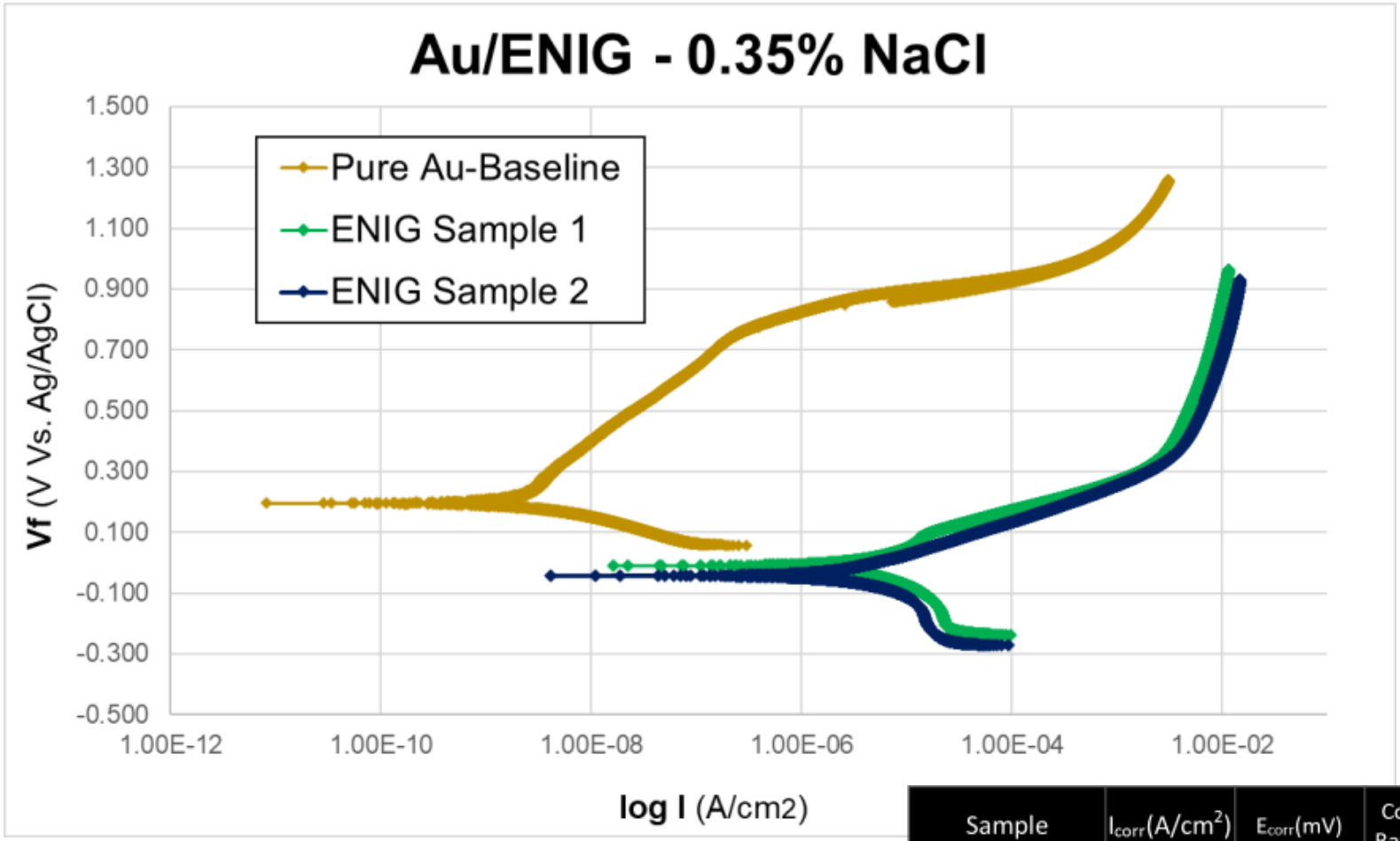
Morphology

SEM/STEM

Josh Kacher
Georgia Tech.

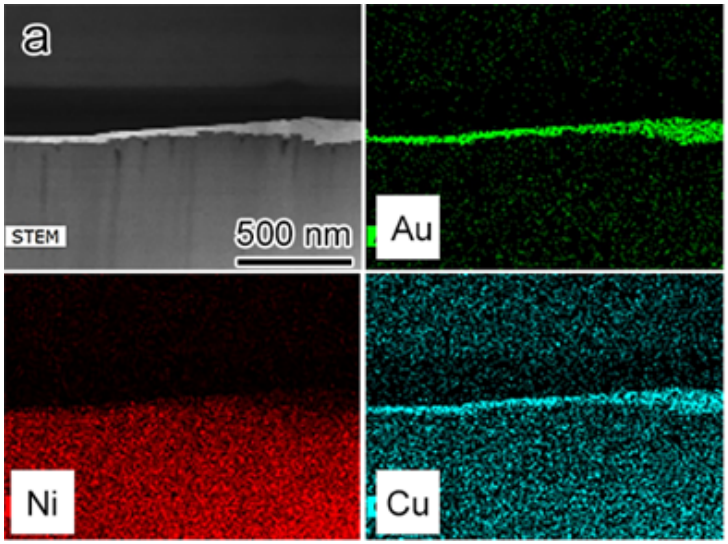
Specified Reqs → Black Box EP Process → "Vendor A"
Black Box EP Process → "Vendor B"

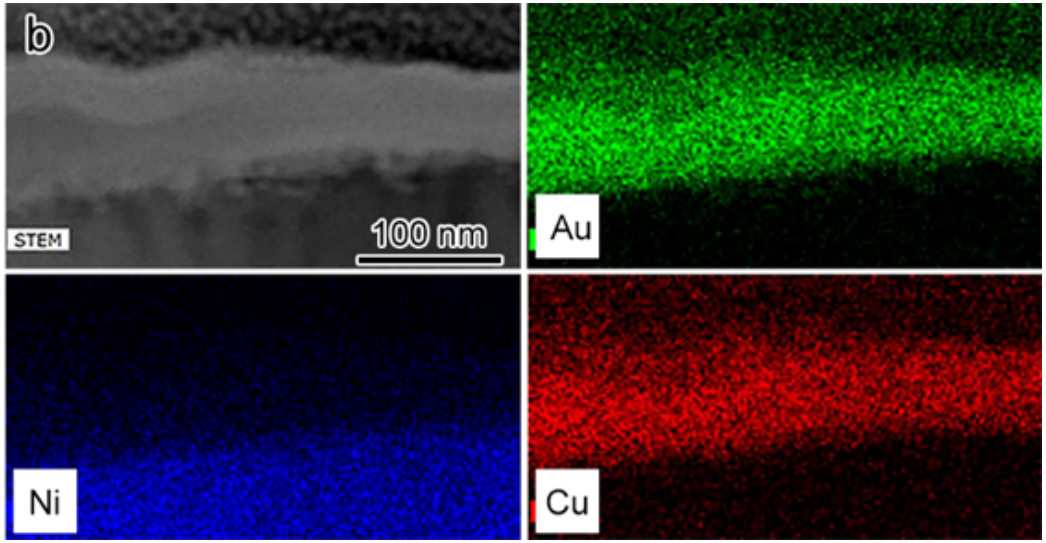
Results (Cyclic Polarization)



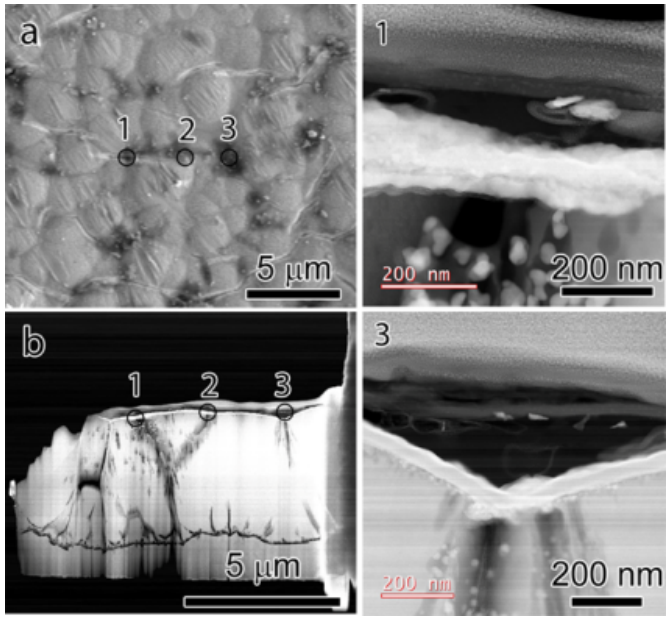
Sample	I_{corr} (A/cm^2)	E_{corr} (mV)	Corrosion Rate (mpy)
Base Au wire	2.1E-09	+190	0.0009
Au Sample A	2.4E-06	-45.7	1.058
Au Sample B	2.6E-06	-10.0	1.150

Results (Scanning/Transmission Electron Microscopies)

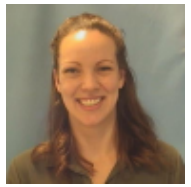




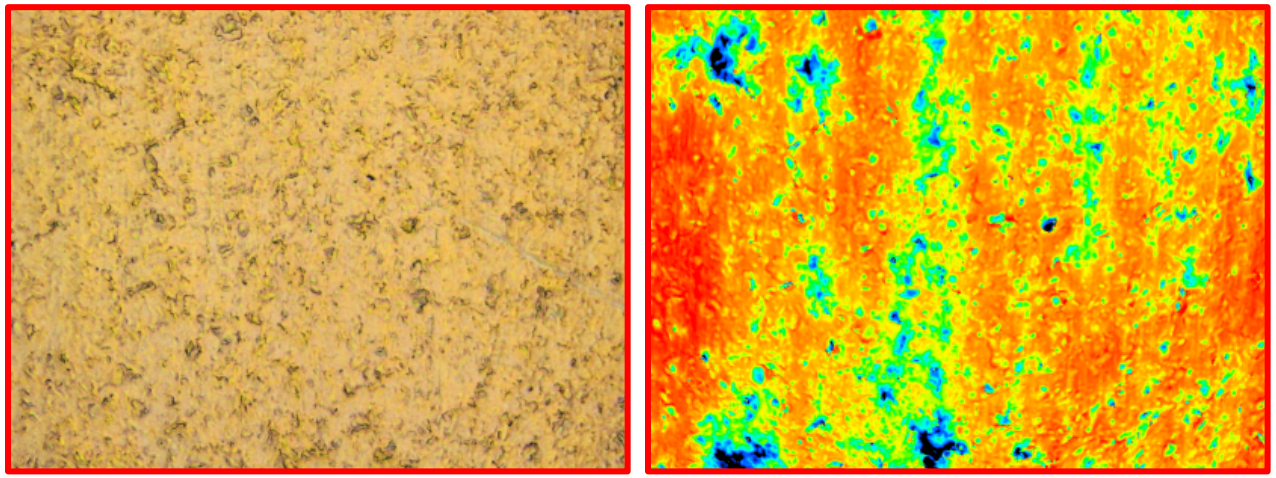
Was noted that one Vendor's samples appeared rougher than the other..

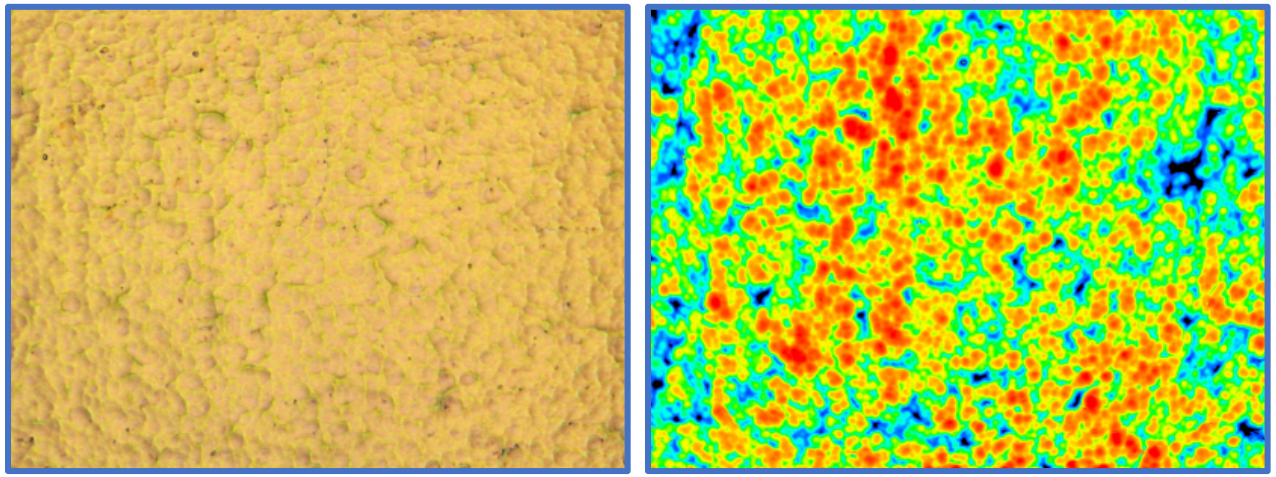


Aside – Surface Topology (Laser Scanning Confocal Microscopy)



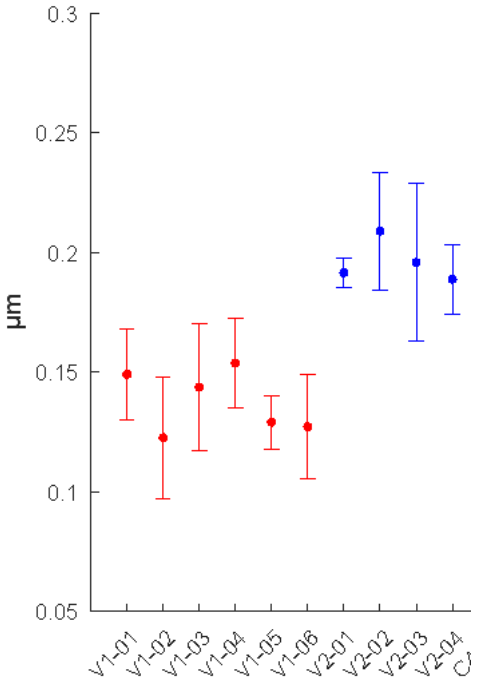
Jessica Faubel
Sandia Nat'l Labs





205 µm

272 µm

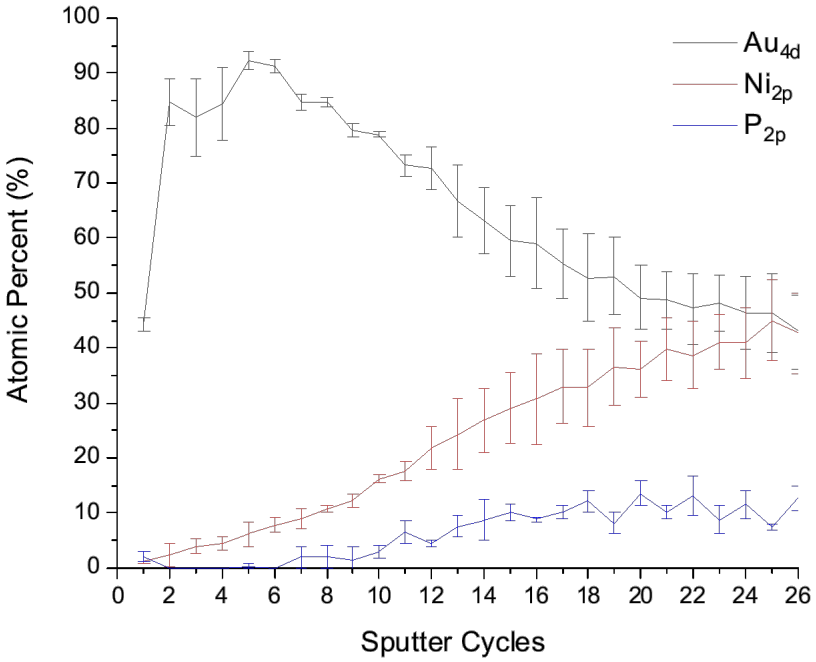


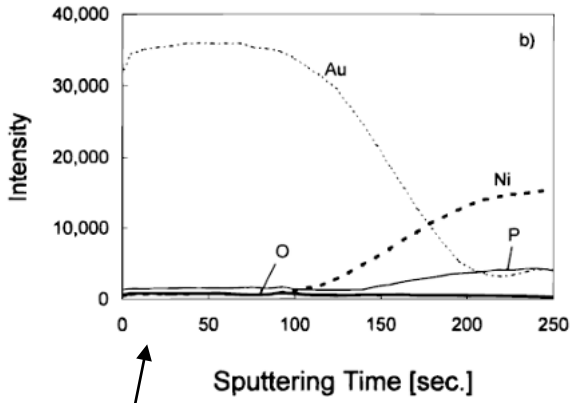
RMS Height

Results (X-Ray Photoelectron Spectroscopy)

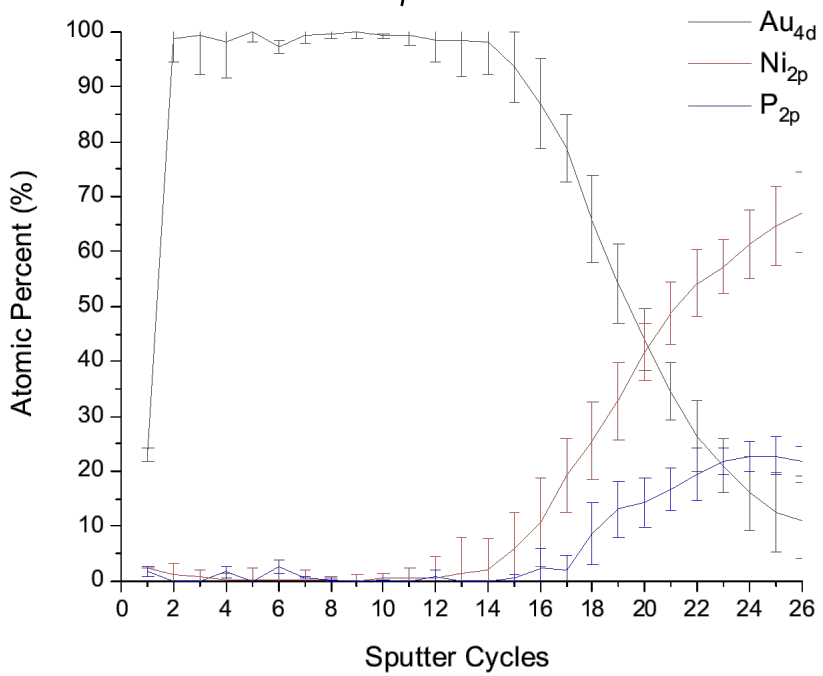
Sample Identifier (Vendor, Spot, Sputter Cycle)	Au 4f %	C 1s %	Cu 2p %	Ni 2p %	O 1s %	P 2p %
Vendor A 1.1	37.88	42.53	3.01	1.26	13.86	1.46
Vendor A 1.2	82.62	10.06	2.56	2.46	2.30	0.00
Vendor A 2.1	50.73	28.21	5.23	0.84	12.40	2.60
Vendor A 2.2	86.63	6.81	2.81	2.24	1.51	0.00
Vendor B 1.1	23.35	48.44	0.56	2.47	24.19	1.00
Vendor B 1.2	98.36	0.00	0.00	1.64	0.00	0.00
Vendor B 2.1	22.71	50.70	0.45	2.38	21.55	2.23
Vendor B 2.2	99.47	0.00	0.00	0.53	0.00	0.00

Results (X-Ray Photoelectron Spectroscopy Depth Profiling)



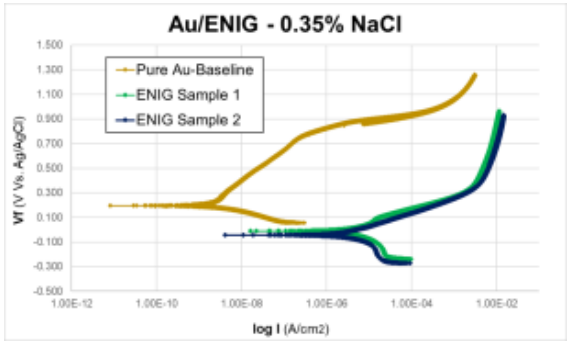


Osaka et. al. 2000
https://doi.org/10.1149/1.1393313



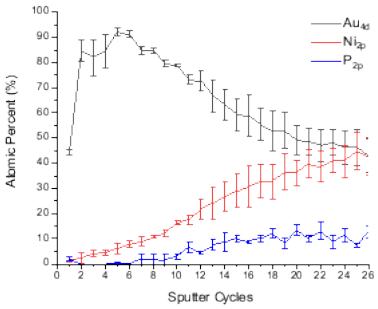
Putting It All Together

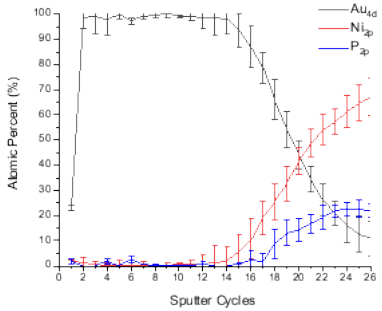
More Similar than Different



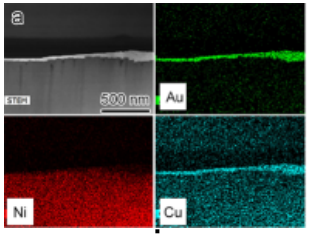
Vendor Samples Have Similar Passivity (or lacktherof)

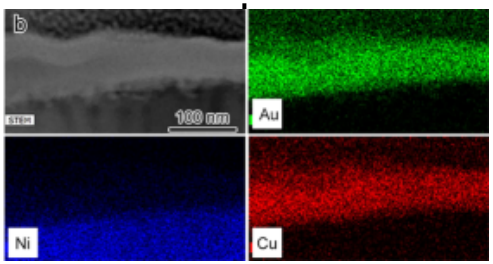
More Different than Similar

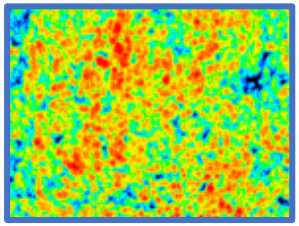


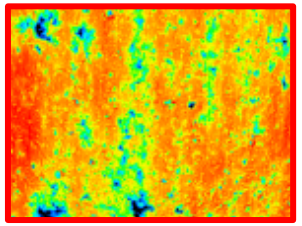


Vendor Samples Have Clearly Different Heterogeneity / Porosity





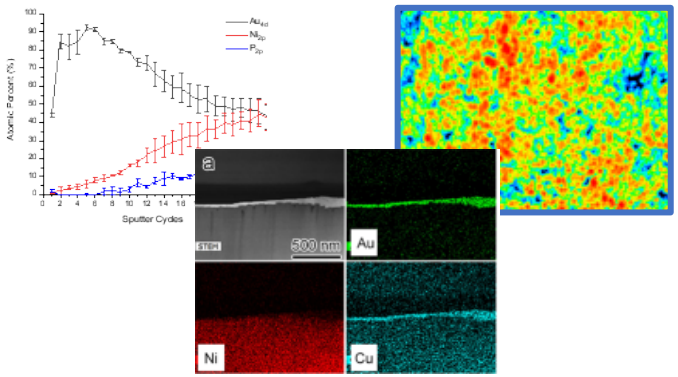




Vendor Samples Have Similar Morphological Defects and Contaminant Chemistry, Different Roughnesses

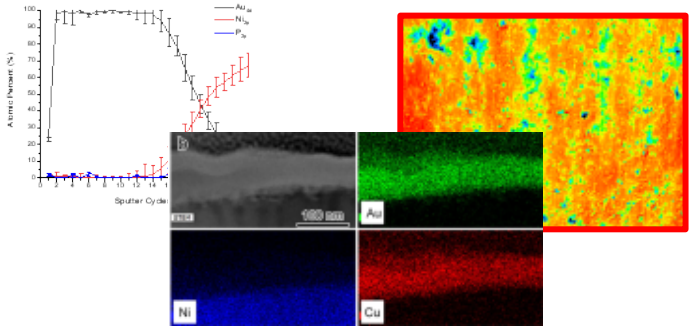
Putting It All Together

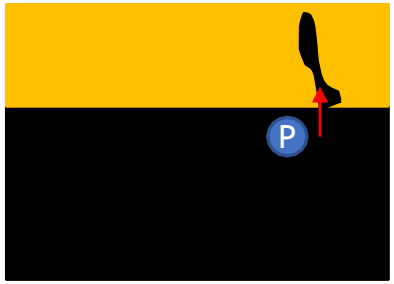
Vendor A



Poorly controlled plating conditions led to high Au porosity, susceptibility to Ni hyper corrosion in sol'n

Vendor B

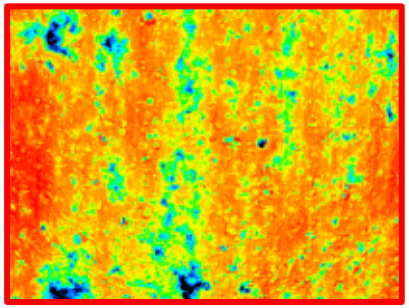


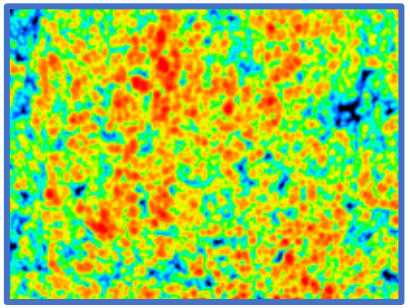


More ideal Au plating conditions, but choice of bath additives may have led to P-enrichment at Ni-Au interface, reducing film passivity

Future Outlooks

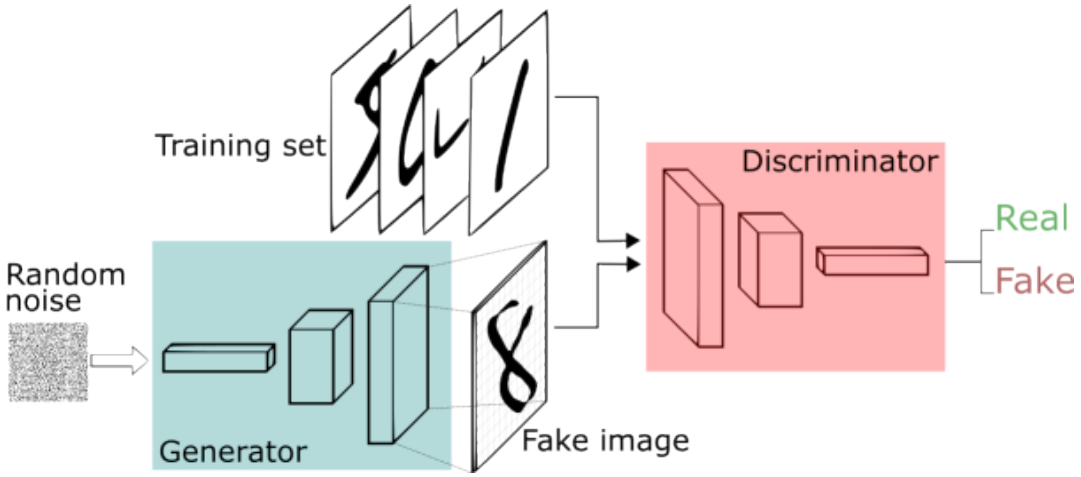
For classifying ‘good’ and ‘bad’… we need a much less comprehensive process





We can clearly see that the surface topology is encoding information about the SEM/TEM learned morphology, as well as the XPS learned ‘porosity’ Electrochemistry is likewise implied by these properties since the layers are sequential and conformal

These latent ‘fingerprints’ of the process-structure-property relationships could allow us to predict performance based on a training set of well characterized samples



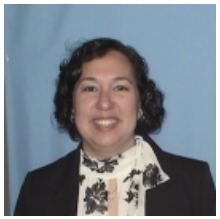
Questions?

Josh Kacher

Jessica Faubel

Preet Singh

Samantha Rosenberg



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Rupesh Rajendran

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Georgia Tech School of Materials Science and Engineering College of Engineering

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Backup Slides

Results (Scanning Vibrating Electrode Technique)