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Ex-Situ, Surface and Bulk Investigations of Defluxing Chemistry Effects on Solder Mask

J. Elliott Fowler[1], Rosario A. Gerhardt[2], Roshaun Titus[2], Miriam Rath[2], Tony A. Ohlhausen[1], Rachel Callaway[1], Samantha G. Rosenberg[1]

[1]*Materials Characterization and Performance Department, Sandia National Laboratories, Albuquerque, NM, 87185*

[2]*Materials Science and Engineering Department, Georgia Tech University, Atlanta, GA, 30332*

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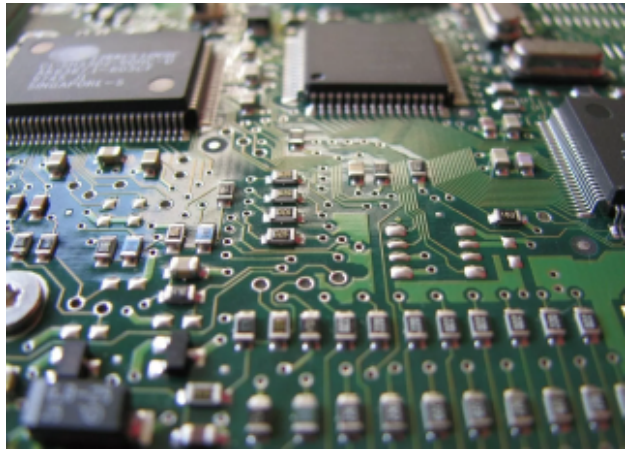
We Rely on Printed Circuit Boards (PCBs) For Everything

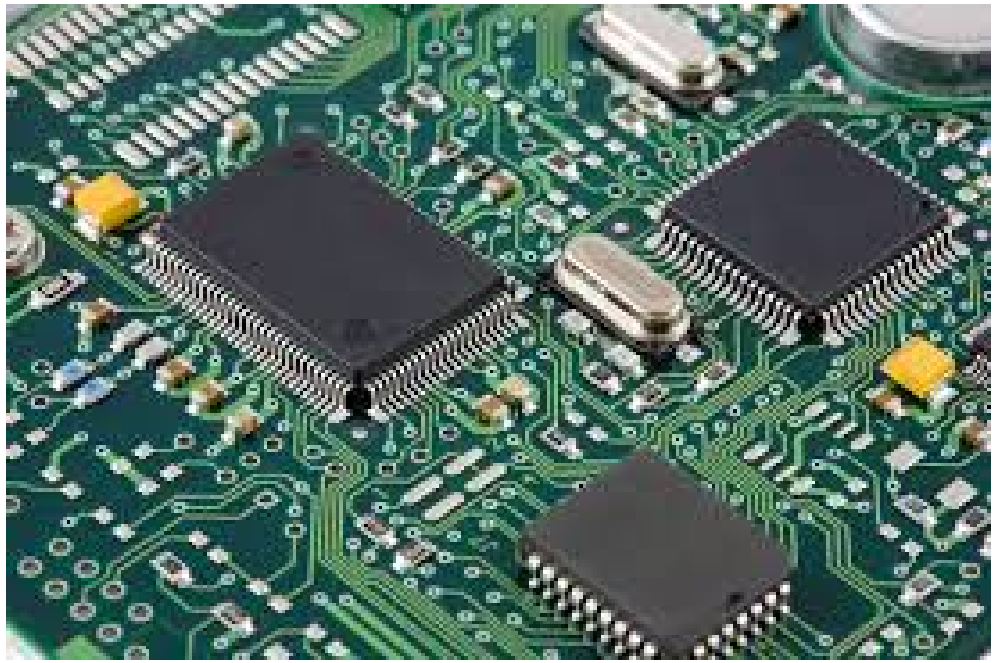


It’s Easy to Treat PCBs As a Black Box

“Black Box”

Inputs

Everything That Goes Into Making and Operating the PCB

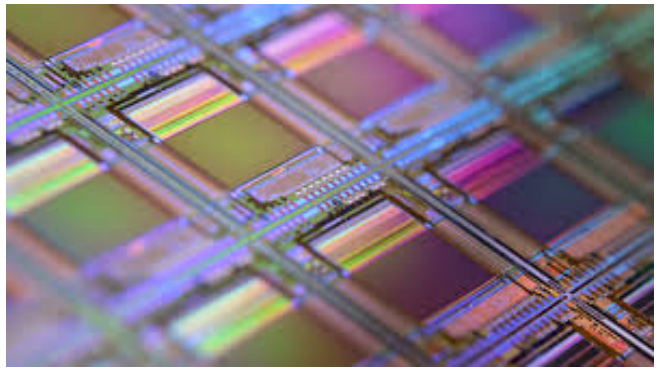


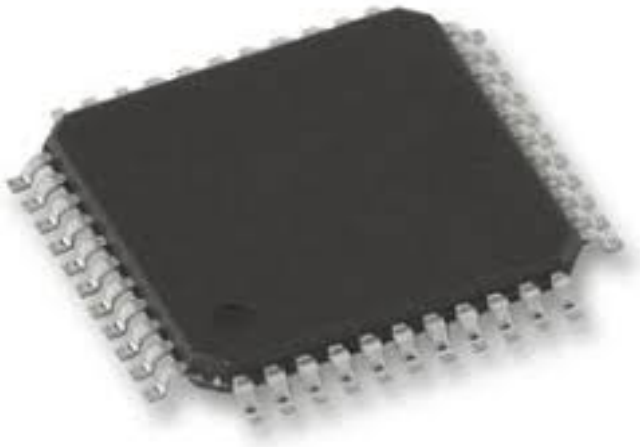
Outputs

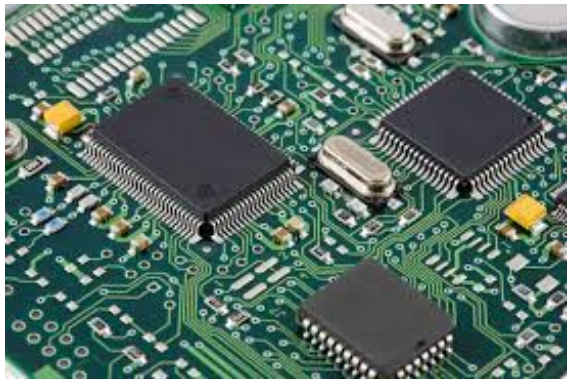
“It Just Needs to Work”

PCBs Materials Complexity is a Compounding Problem

SCALE	Nano -> Micro	Micro -> Milli	Milli -> Macro



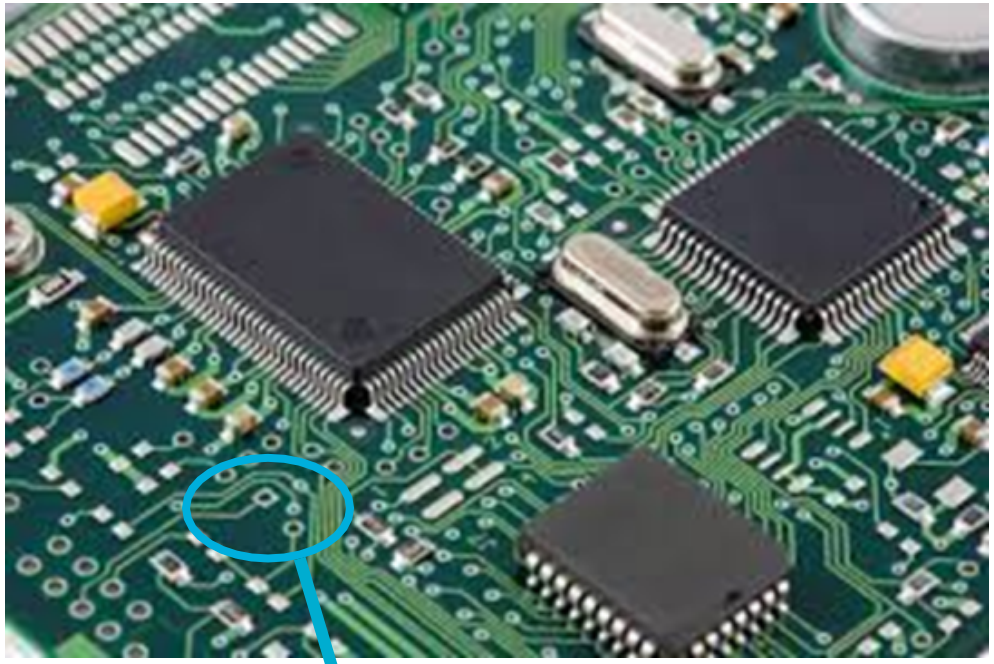




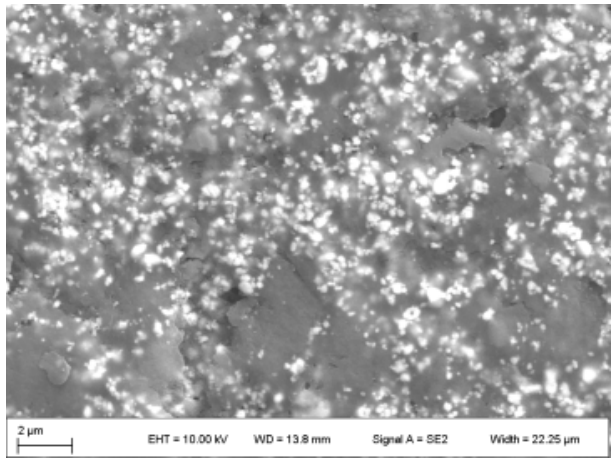
# Materials	10^0 - 10^1	10^1 - 10^2	10^2 – 10^3+

Solder Mask is a Heterogeneous Material

What is Solder Mask?
(Liquid-Photoimageable Variety, Most Common for SMT)



Solder Mask is all this green stuff



SEM Image of LPI Solder Mask –
Taken @ Sandia National Labs

Made up of:

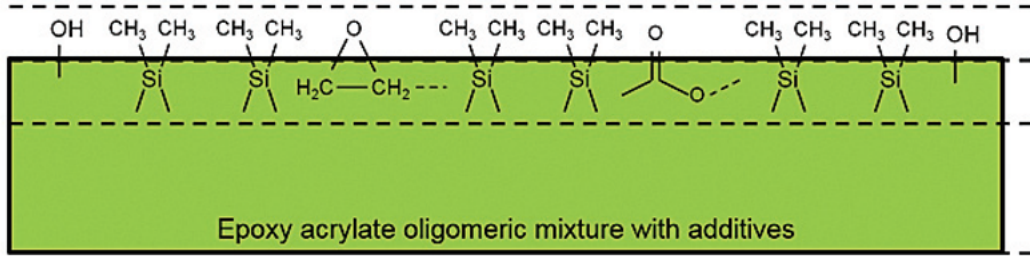
- Epoxy Acrylate Resin
- Hardener Chemistry
- Numerous Fillers and Additives
  - Quartz, SiO2 for viscosity
  - Barium Sulfate for flame resistance
  - PDMS for optimal surface tension, spreading

Heterogeneous Materials Behave Uniquely

Heterogeneous materials can have wildly different chemistries at a local level

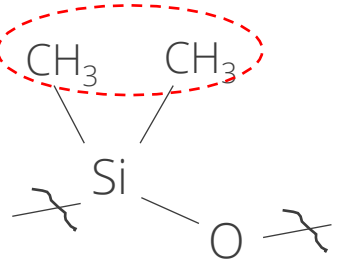
Surface rich in PDMS[1]

Bulk more representative of mixture, but can still have substantial localized chemical variability



Surface chemistry dictates materials' interaction with external environments

Polydimethylsiloxanes (PDMS)



Externally-oriented methyl groups make surfaces more hydrophobic (water hating)

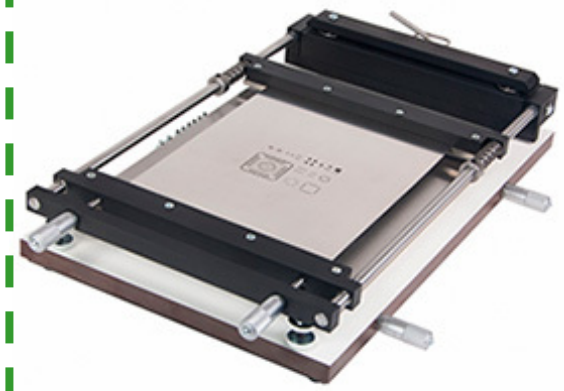
This is good for reducing moisture uptake! Especially considering there is a negative linear relationship between moisture content and capacitance of solder mask material[2]

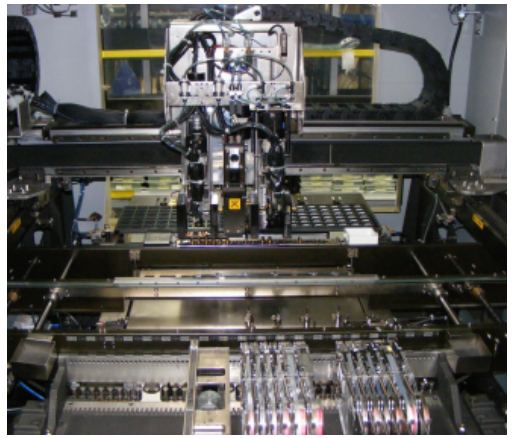
1) Hofmeister, C., et al., Materials Chemistry & Physics (2017) 185, 129
2) Pecht, M. G., *et al.*, *IEEE Transactions on Components Packaging Technologies* (1999) **22** (1), 104

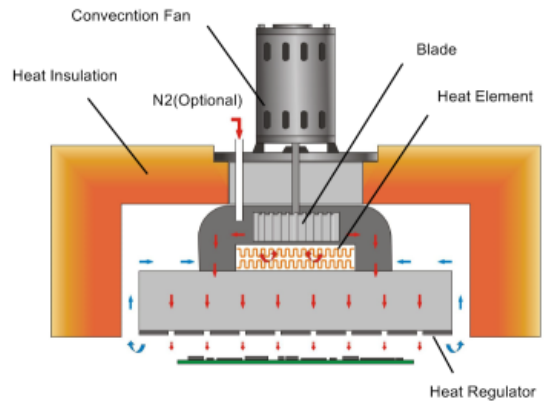
PCB Assembly – 10000 ft. Level

Lots of effort put here developing better metallurgy and methodology to advance Moore's Law

Yes, most PCBs are washed in AQUEOUS solutions!







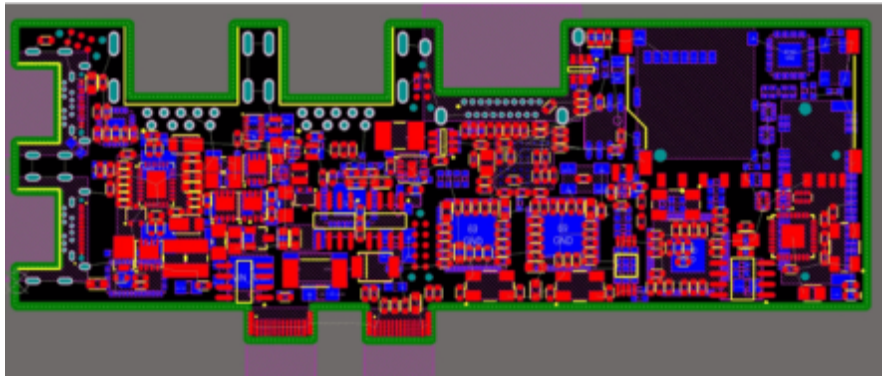
Modern Soldering Flux

What is flux? Five general chemical components:

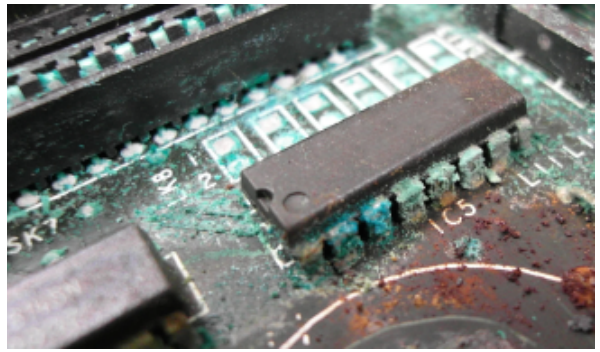
- Rosin
- Resin
- Activators
- Halides
- Surfactants

Pesky Moore's Law…

When we started shoving smaller and smaller devices together as densely as possible…



Corrosion!



<u>Solution –</u>
Swap Halides for Weak Organic Acid Activators

<u>Consequences -</u>

- pH of Flux Plummets
- Cleaning Chemistries Must Become Highly Alkaline to Counterbalance

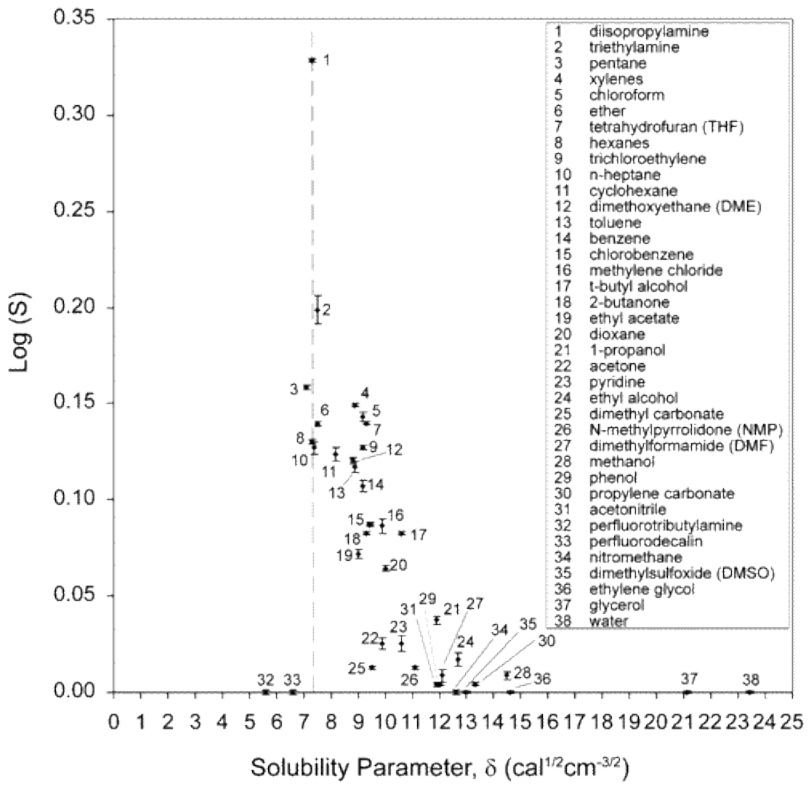
Hypothesis

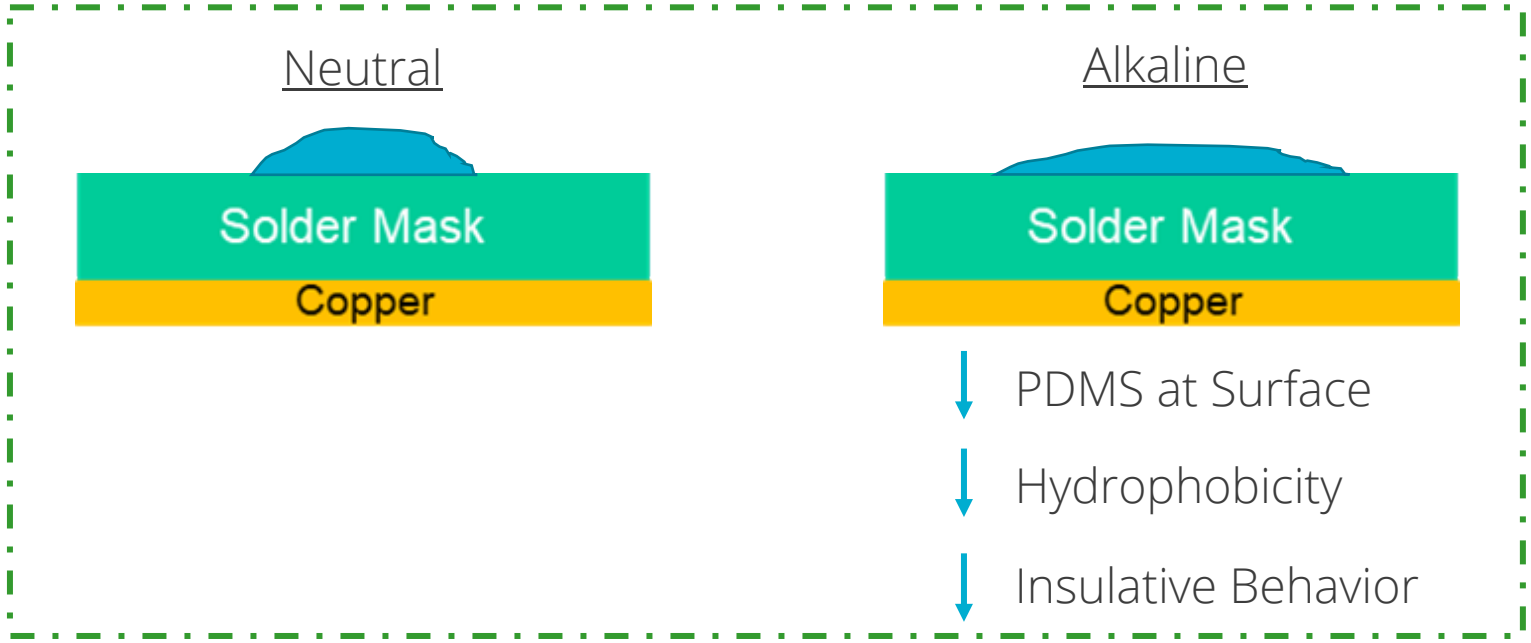
Increasing Alkalinity

~7 → ~12

DI Water — ‘pH Neutral’ — Alkaline

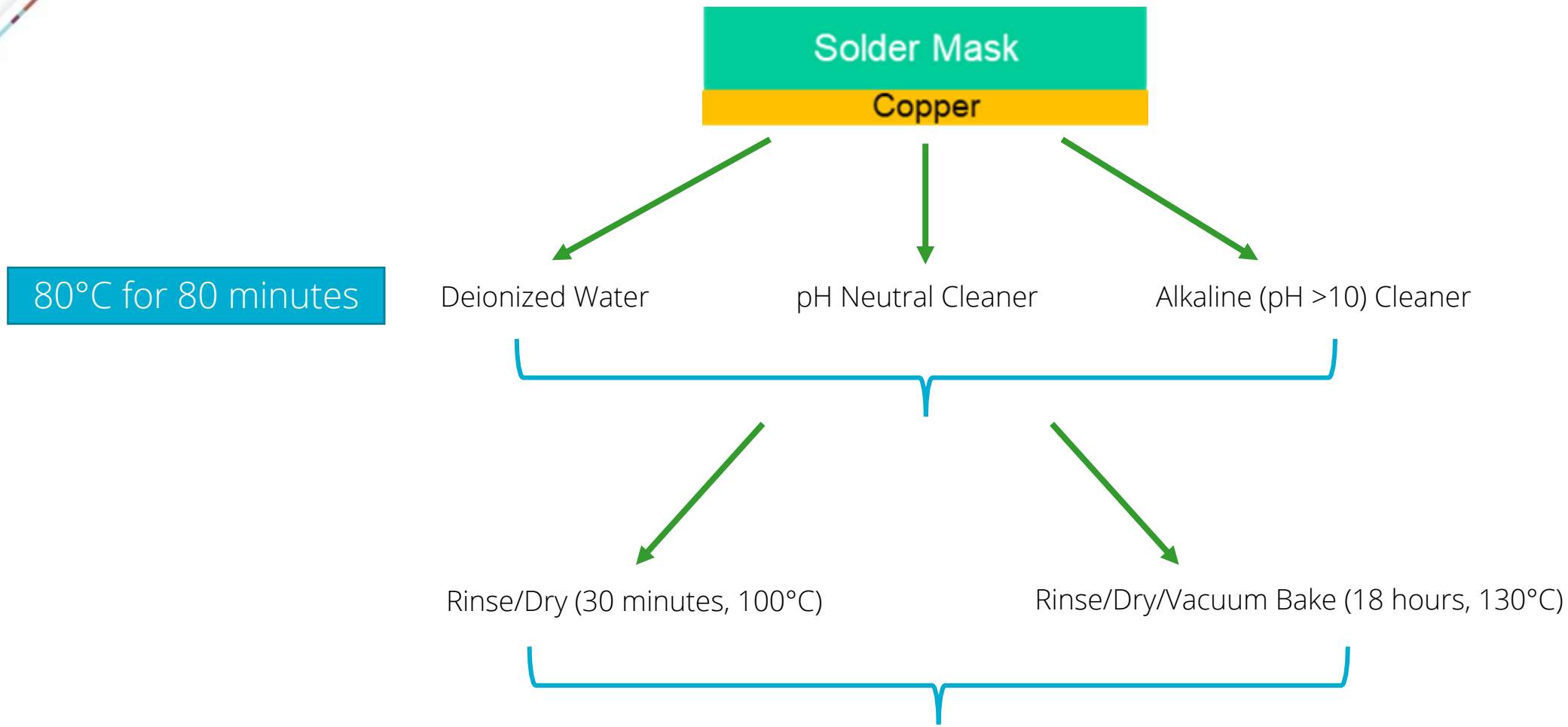
More alkaline chemistries will remove or modify the surface chemistry of the solder mask





Lee, J. N., *et al.*, *Analytical Chemistry* (2003) **75** (23), 6544

Experimental Design

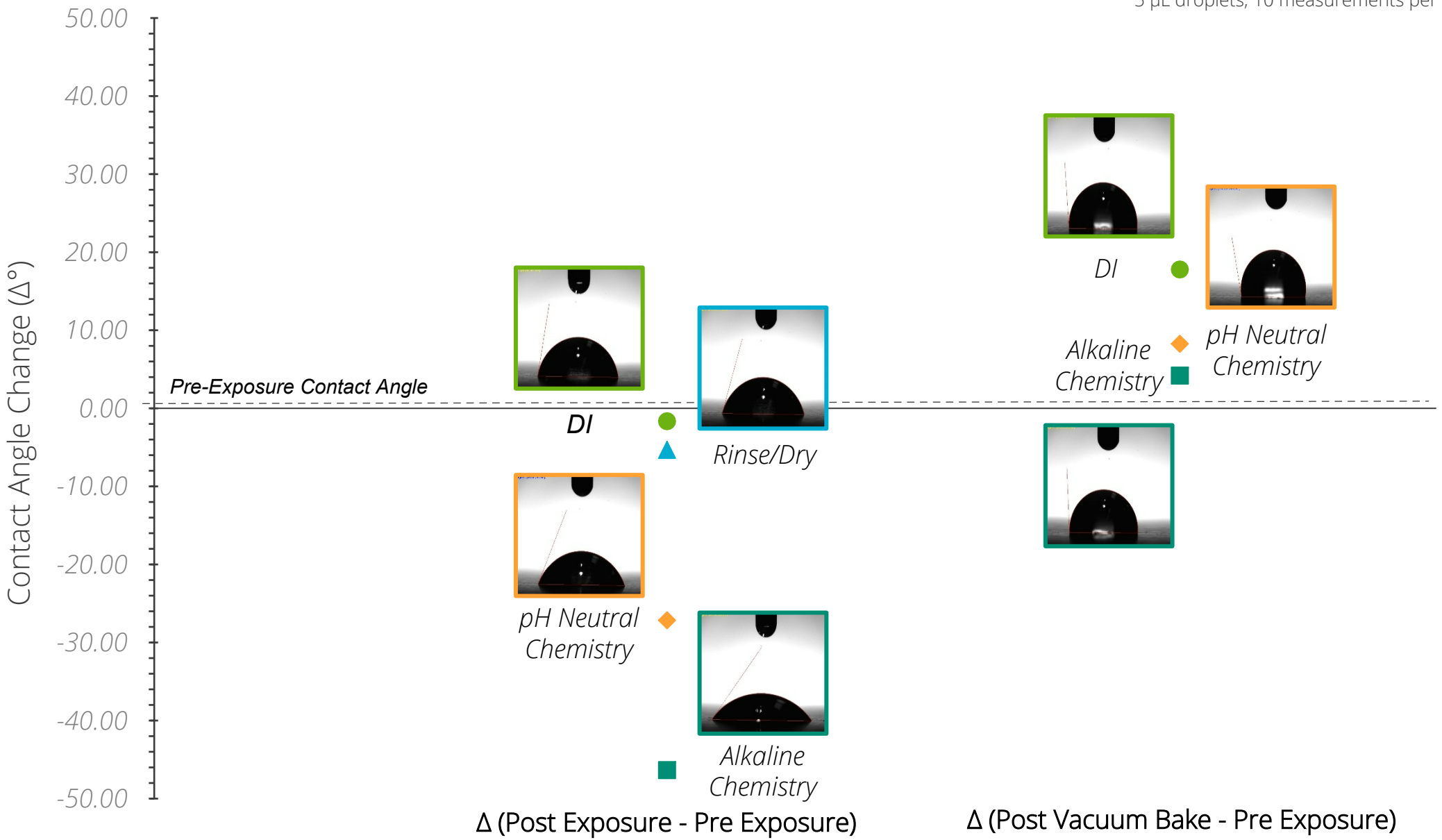


Perform Analysis:

- Water Contact Angle
- Time-of-Flight SIMS
- X-Ray Photoelectron Spectroscopy
- Electrochemical Impedance Spectroscopy

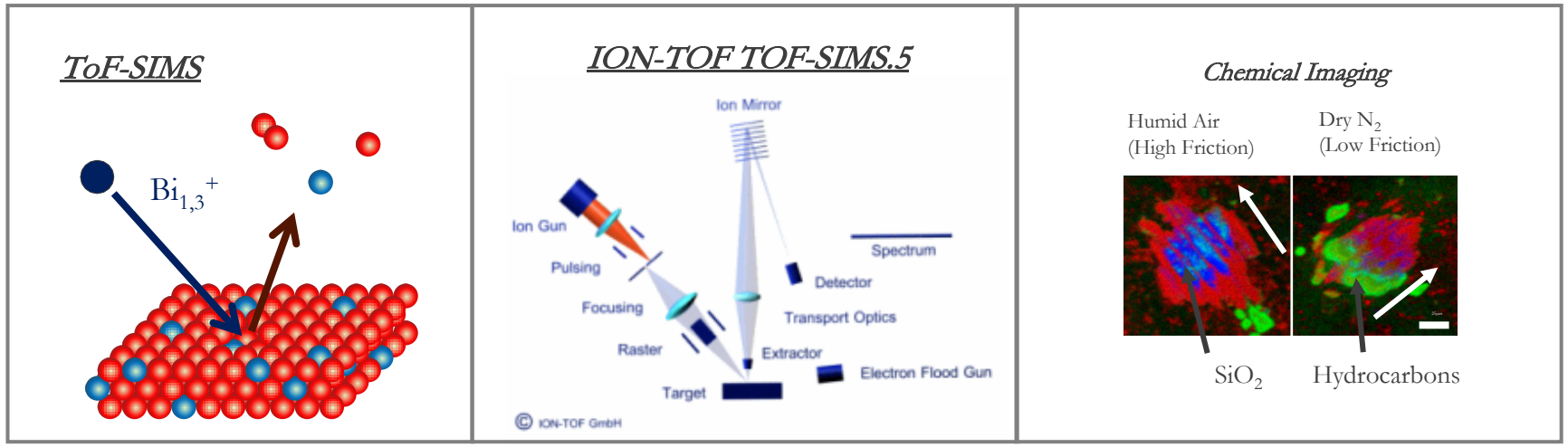
Contact Angle Goniometry

5 µL droplets, 10 measurements per sample, outliers removed



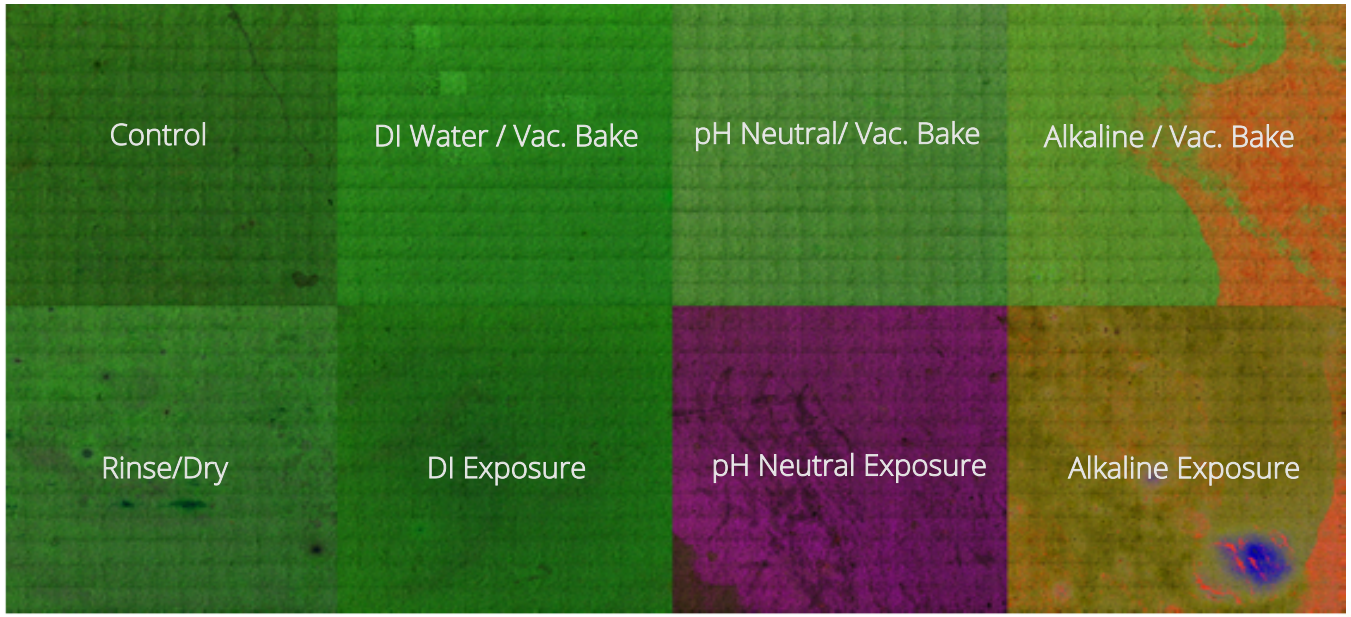
Time of Flight Secondary Ion Mass Spectrometry

ToF-SIMS analyzes material ion fragments from ion bombardment

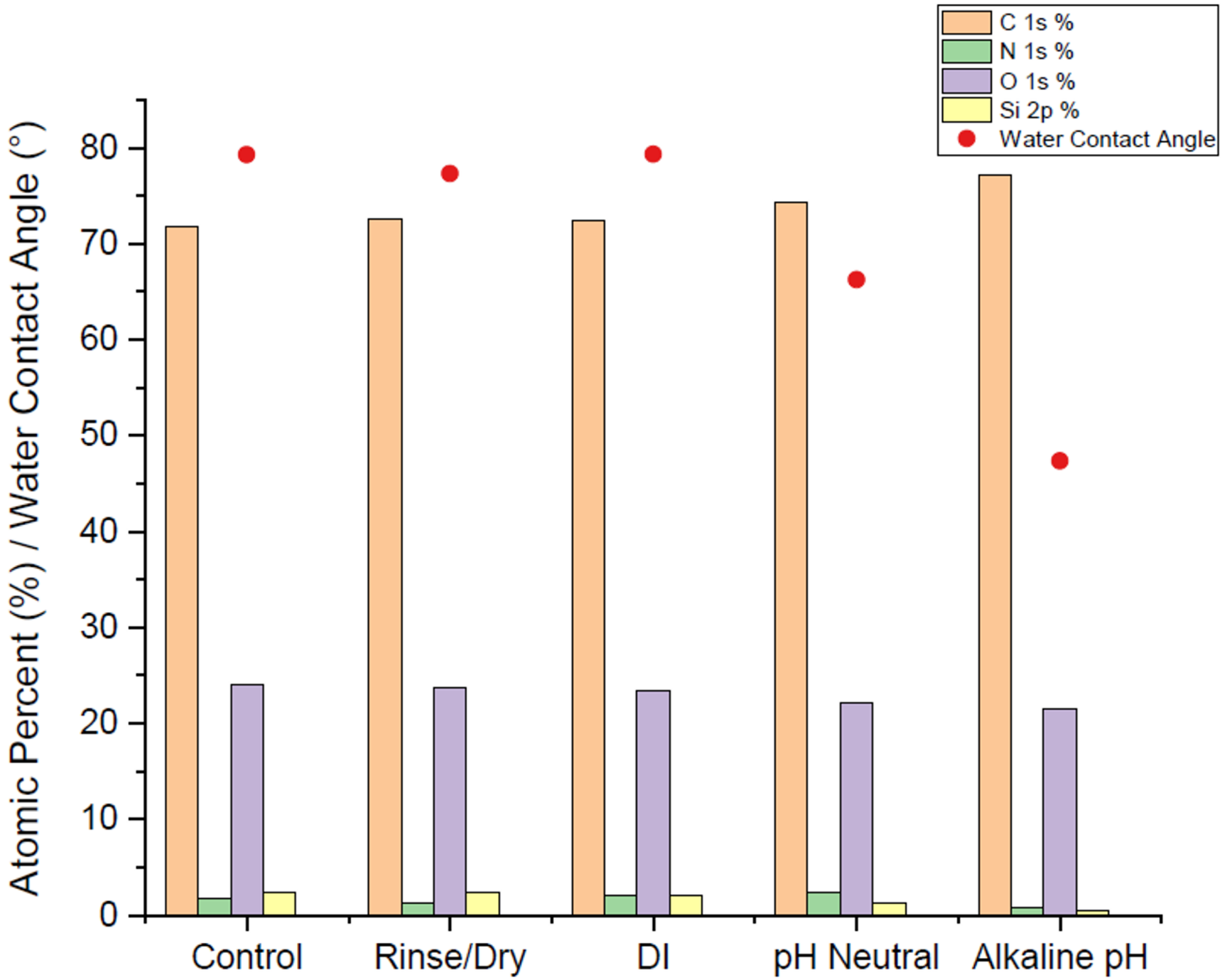


5x5mm^2 area 15x15 patches resulting in 255x255 pixels, 40 shots per pixel

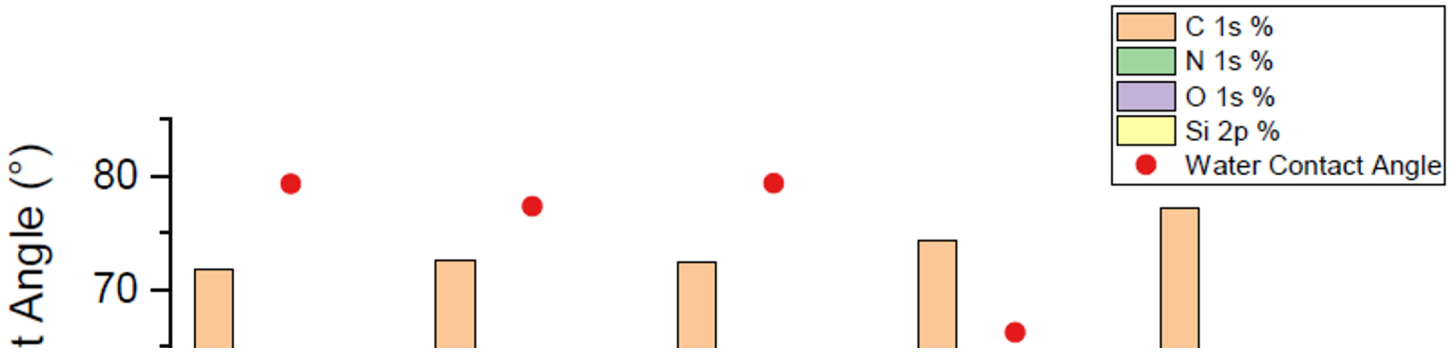
Green: Silicones
Magenta: Unique (pH neutral) organics
Yellow: Unique (Alkaline) organics



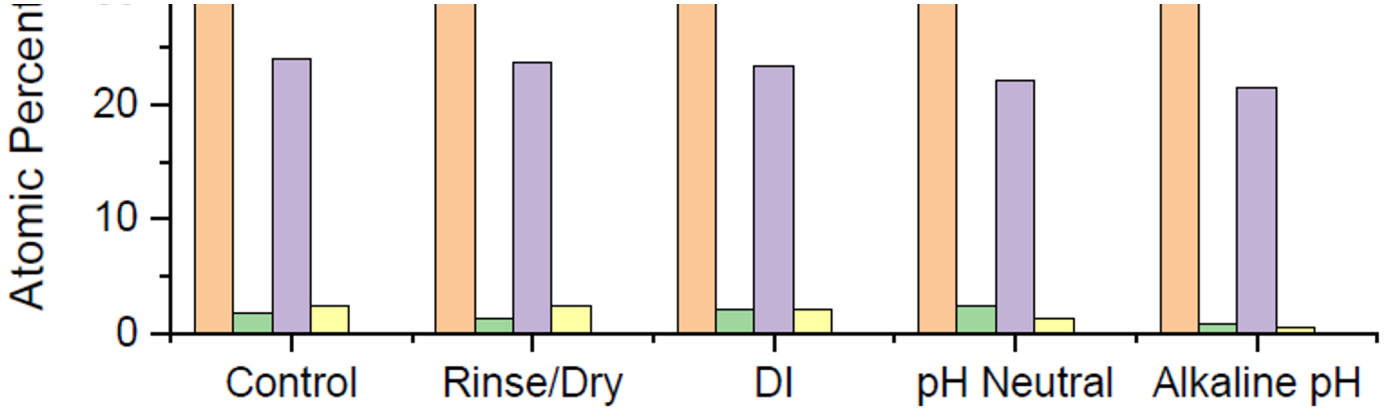
X-Ray Photoelectron Spectroscopy



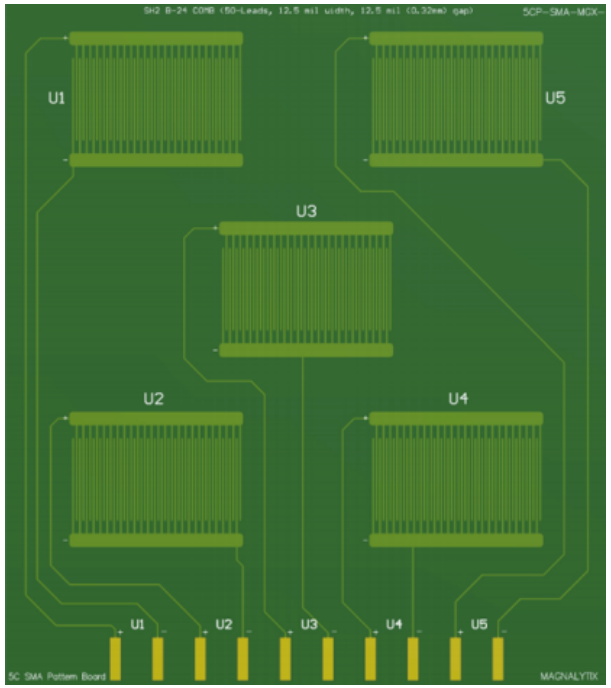
X-Ray Photoelectron Spectroscopy



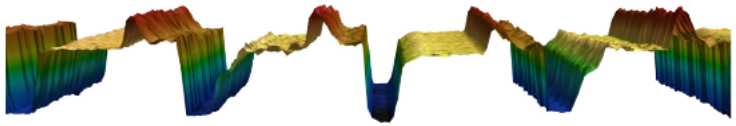
Atomic Composition (%)					
	C 1s %	N 1s %	O 1s %	Si 2p %	Water Contact Angle
Control	71.72	1.74	24.07	2.47	79.30
Rinse/Dry	72.61	1.26	23.72	2.41	77.30
DI	72.35	2.13	23.46	2.06	79.32
pH Neutral	74.31	2.29	22.20	1.20	66.23
Alkaline pH	77.17	0.77	21.56	0.49	47.34



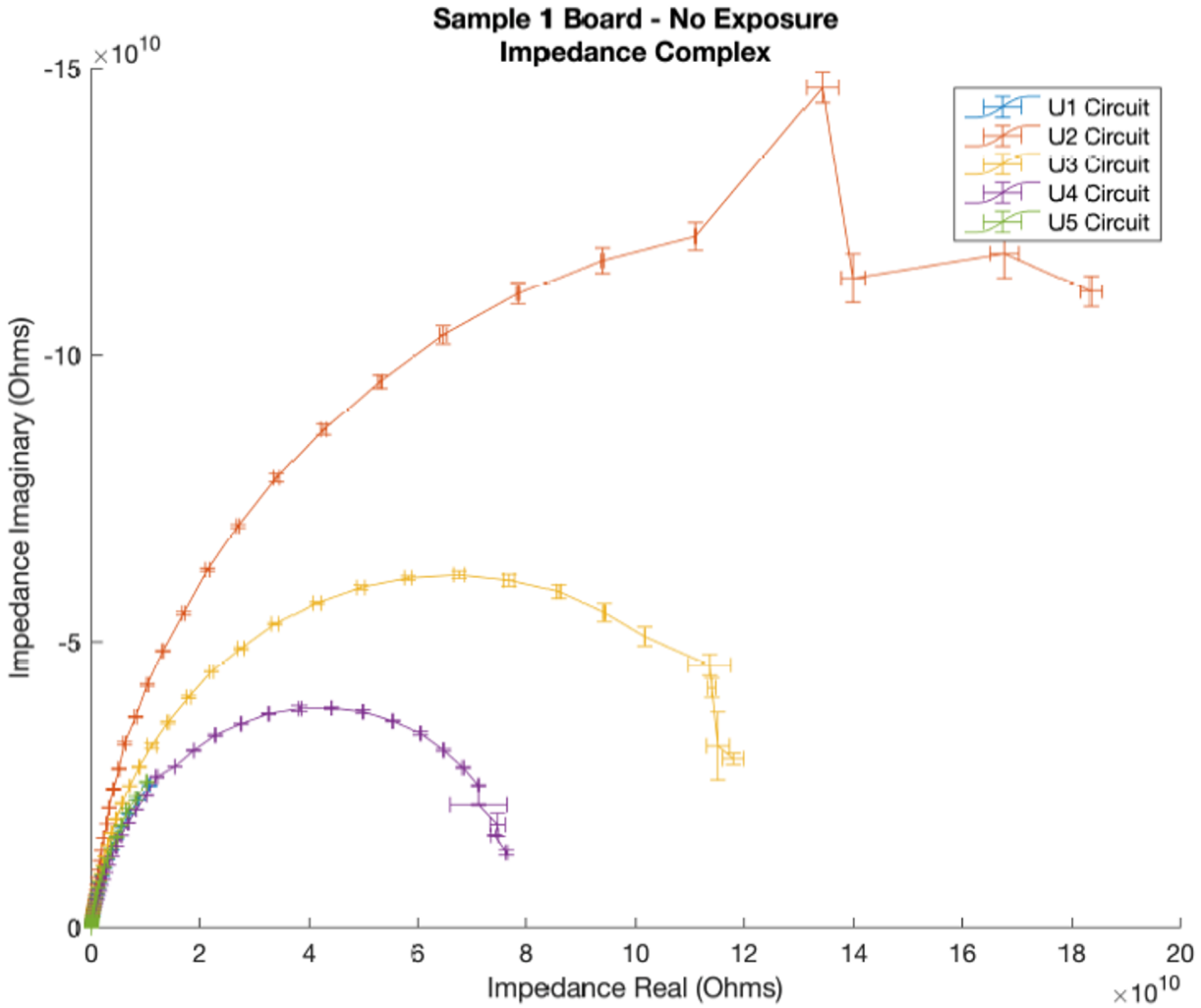
AC Electrochemical Impedance Spectroscopy



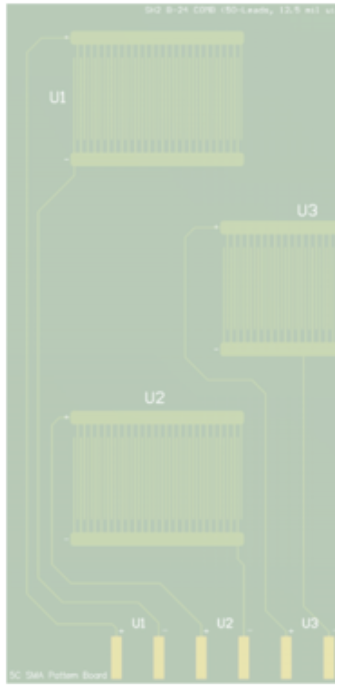
EIS Test Sample – 5 identical comb patterns



2D Profile of Surface Topography of Comb Section (Collected via Laser Scanning Confocal Microscopy)



AC Electrochemical Impedance Spectroscopy



EIS Test Sample – 5 patter

2D Profile of Surface Section (Collected via Laser Scanning Confocal Microscopy)

Impedance Spectroscopy for Quality Testing of Interdigitated Circuits

Roshaun Titus
School of Materials Science and Engineering
College of Engineering, Georgia Institute of Technology
Atlanta, Georgia. United States
rtitus6@gatech.edu

Rosario A. Gerhardt
School of Materials Science and Engineering
College of Engineering, Georgia Institute of Technology
Atlanta, Georgia, United States
rosario.gerhardt@mse.gatech.edu

J. Elliott Fowler
Sandia National Laboratories
Alburquerque, New Mexico, United States
jfowle@sandia.gov

***Abstract*—Electronic components are affected by several factors, some of which include temperature and relative humidity of the environment of operation. When fabricating multiple identical components, it is important to ensure all variables involved in the fabrication of each component are equal. Impedance spectroscopy as a tool holds potential in verifying whether components are identical to one another, as it can test a material's response using AC voltage throughout a range of frequencies. In this paper, impedance spectroscopy is used in quality testing two boards with interdigitated circuits fabricated at Sandia National Laboratory. Statistical methods are performed to share the referenceable numerical differences between the circuits on a board throughout the frequency range. It was found evident that significant differences existed between the circuits on a single board. Tests were also done at varying relative humidity levels to highlight its effect on circuit operations. Frequency and relative humidity were found to play a critical role in the behavior of the circuits.**

Keywords—impedance, frequency, humidity, error, repeatability, reproducibility.

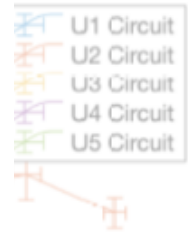
I. Introduction

Impedance spectroscopy was used to characterize several solder masked circuit boards with interdigitated circuits fabricated at Sandia National Laboratory. Each circuit contained response. Measurements were done under normal laboratory conditions of relative humidity and temperature to represent sample responses under easily repeatable conditions. Investigated are the similarities and differences of the uncoated non-exposed boards in terms of statistical relations between measurements of a single circuit and measurements of all five circuits on two different boards.

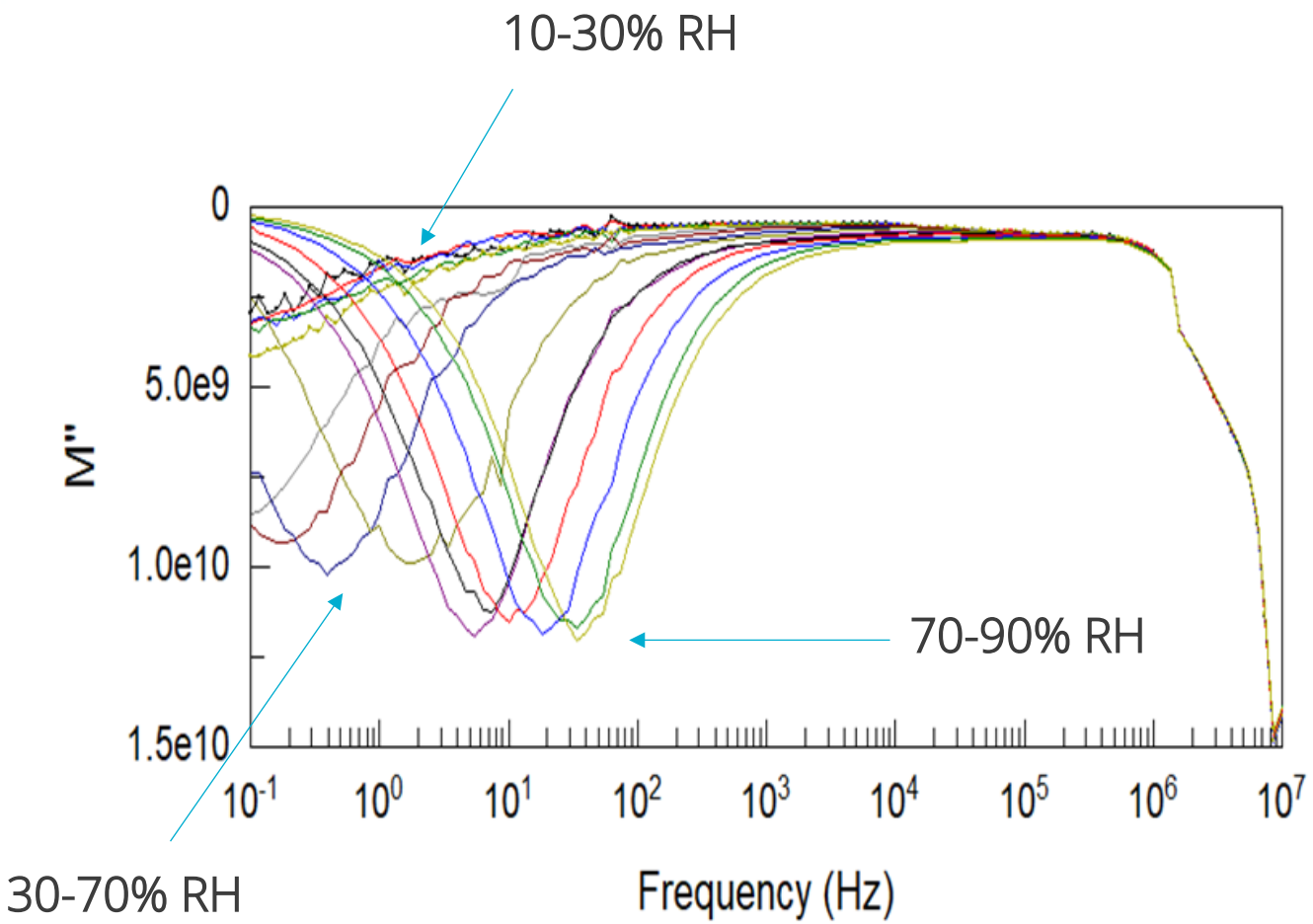
II. Methods

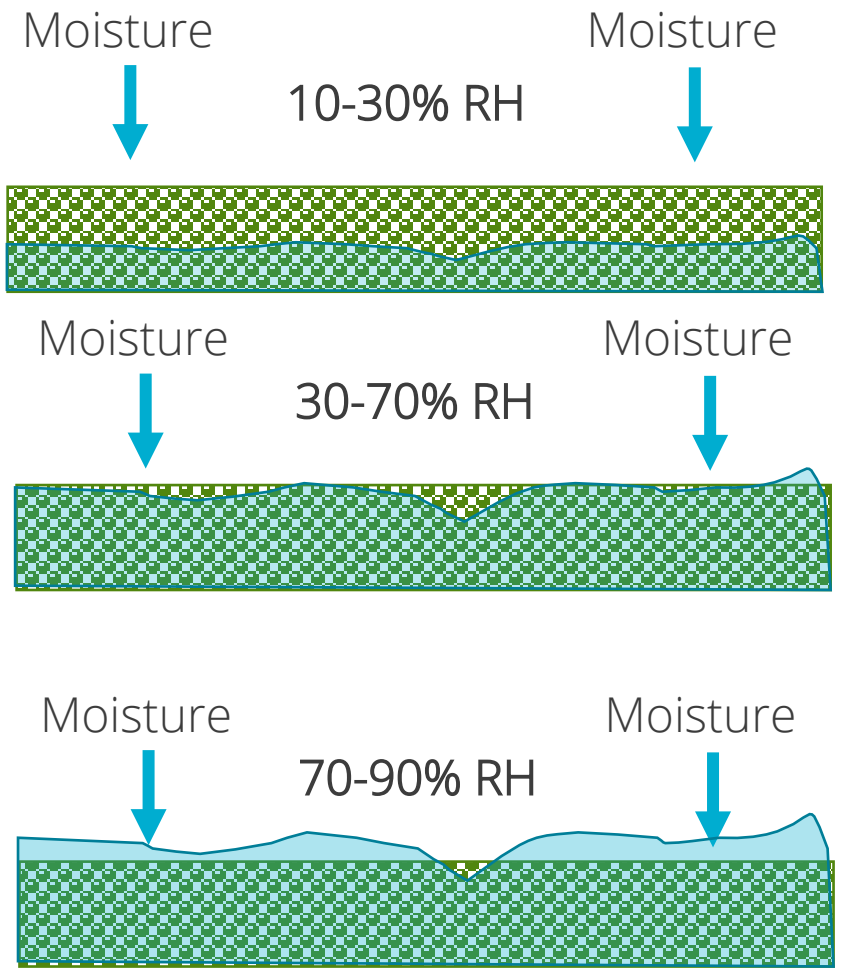
A. Impedance Spectroscopy

Impedance measurements were done using a Solartron SI 1260 and Solartron 1296 Dielectric Interface, operated using SMaRT Impedance Measurement software. Measurements were done for the five circuits on each board. Three runs or tests were performed per circuit to verify the impedance response being measured, which were further reviewed using ZView Impedance Software. One such measurement spectrum is depicted in Fig. 3 for Sample8 at circuit U2. Measurements were performed at an AC voltage of 500 mV through a frequency



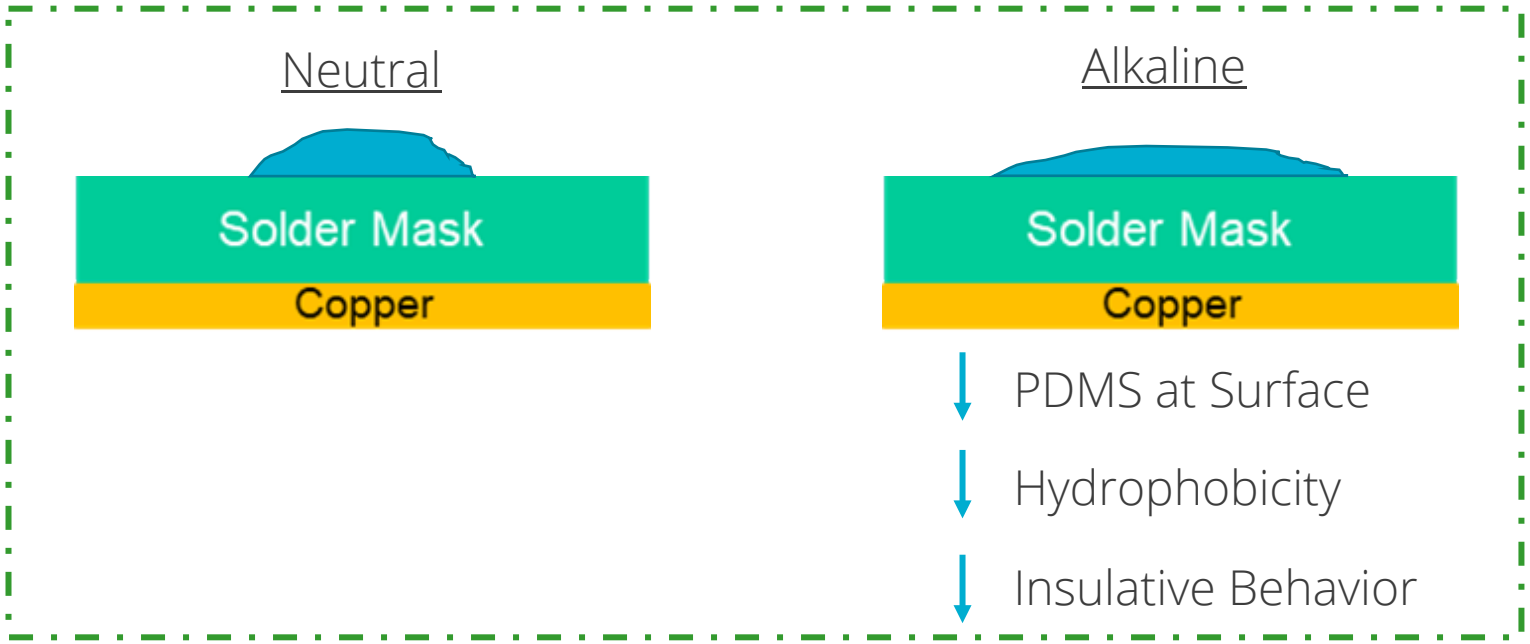
AC Electrochemical Impedance Spectroscopy



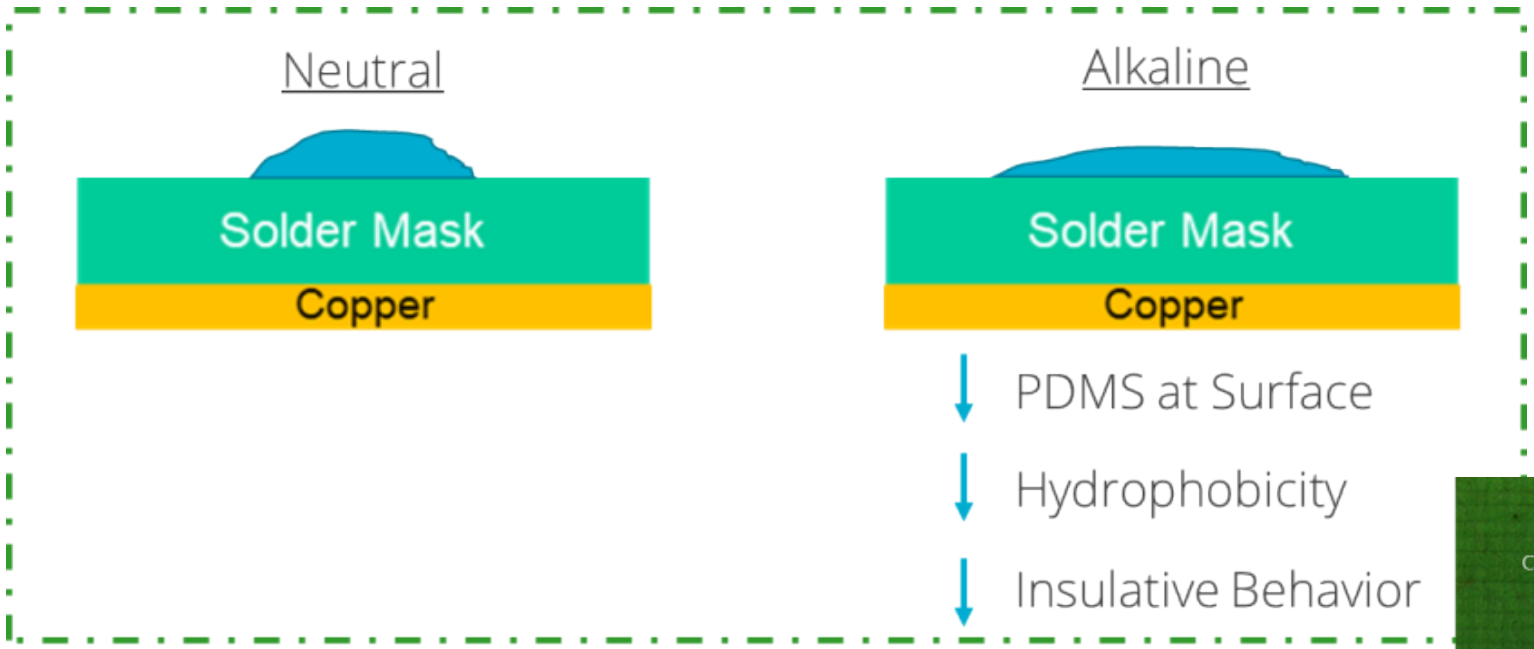


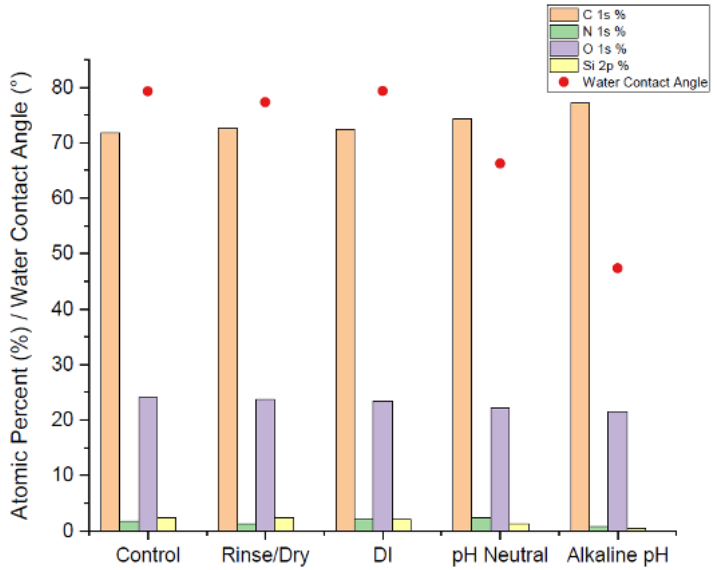
Due to variations in void volume, topography and other 'saturation' factors locally for each sample, difficult to disentangle effect of surface chemistry from other factors in terms of impedance response

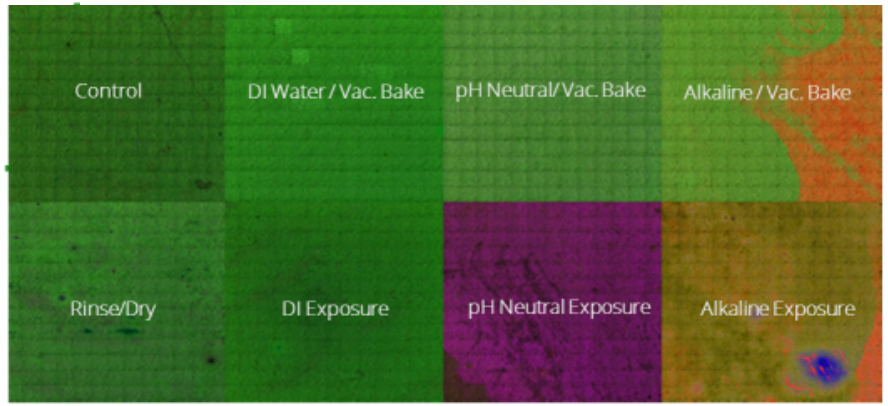
Conclusions



Conclusions







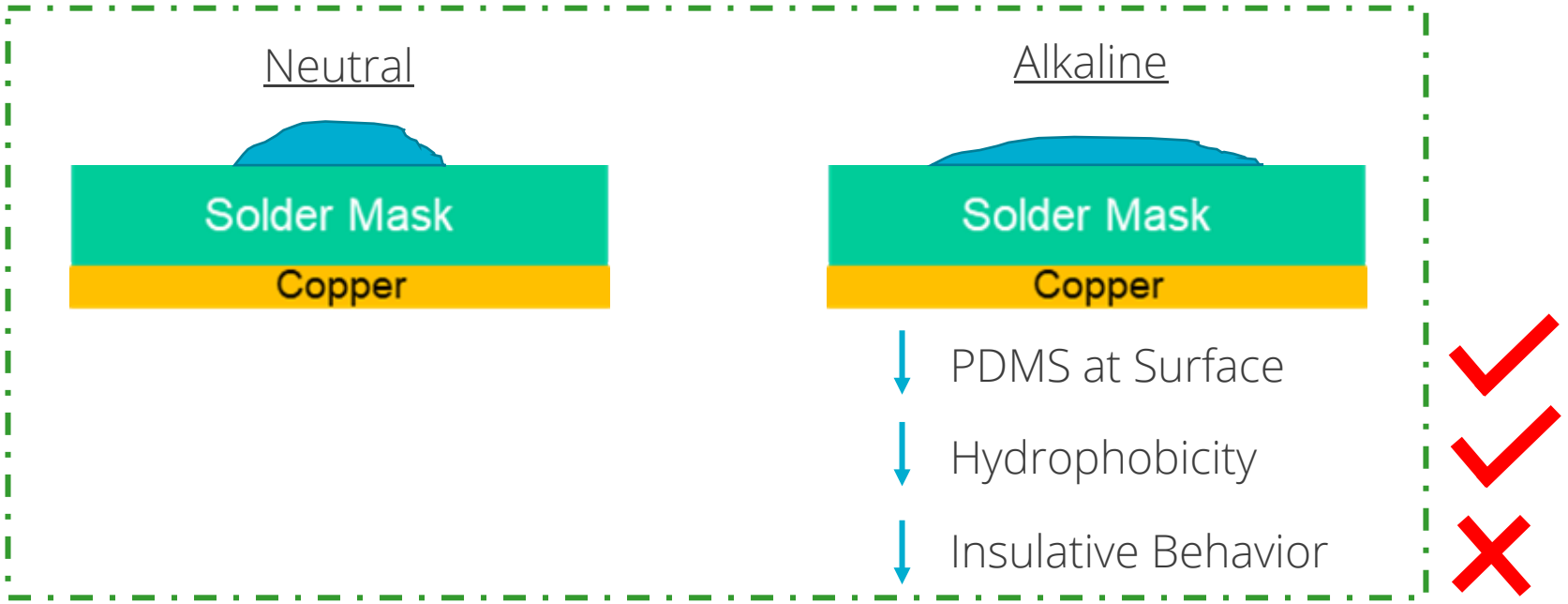
Conclusions

Neutral

Alkaline

- PDMS at Surface
- Hydrophobicity
- Insulative Behavior

Conclusions



Irreversible Changes to the Surface Chemistry Still Have Downstream Effects (E.G. Adhesion of Coatings) But Still Unclear How Bulk Dielectric Properties Are Affected

Questions?

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