COVALENT METROLOGY

Welcome

COVALENT METROLOGY

Solving Puzzles Using Metrology: Case Studies in Troubleshooting When (1+1) > 2

Speaker

Dr. Chris Moore,
Vice President, Technology

April 22, 2021 | 11am PT

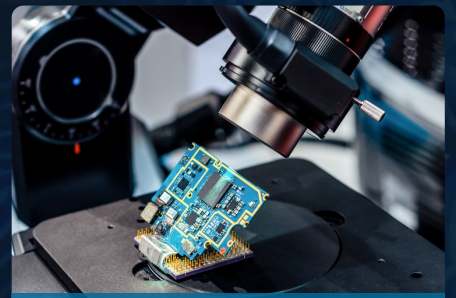
COVALENT ACADEMY

Episode 21



COVALENT METROLOGY

Silicon Valley-based analytical labs and platform delivering quality data and expert analysis for advanced materials and device innovation



Comprehensive Solutions Stack

40+ cutting-edge instruments, offering 100+ Techniques

Analytical Services

Advanced Modeling

Method Development

Temp. Staffing Solutions



Affordable and Fast

Fast Turnaround Times, No Expedite Fees

Volume Savings

Instant Access to Data and Reports in Secure Portal



Flexible Business Model

Custom Consulting Solutions and Certified Onsite Support

Training and Certification on Instrumentation

Co-op and Tool-Share Opportunities

Laboratory Audits

Rich Network of Partnerships

Rigaku · J.A. Woollam · ThermoFisher SCIENTIFIC · PVA TePla · Anton Paar · Asylum Research an Oxford Instruments company

Partner to World's Leading Instrument Manufacturers and Labs

Expanding Instrumentation, Lab Connections and Learning



Who We Are, Who We Serve

500 Clients + 40-60 New Clients/ Quarter

40 People, 13 PhDs

Cutting-edge Analytical Capabilities

24,000 ft^2 Lab in Sunnyvale, CA

Covalent Technical Groups and Organization

COVALENT METROLOGY

PCBA, Semiconductor, and Electronic Device Metrology & Failure Analysis

- DPA / Mechanical Cross-section
- Dye & Pry Test
- Hot Spot Detection
- IR Imaging / Emission Microscopy
- Root-Cause Failure Analysis
- EBIC / OBIC failure analysis

+ many more advanced methods!

Electron / Scanning Probe Imaging & Microscopy

- SEM (+ EDS)
- FIB-SEM (+ EDS)
- S/TEM (+ EDS / + EELS)
- AFM & Advanced AFM Modes
- Scanning Acoustic Microscopy (SAM)

Optical Microscopy & Spectroscopy

- Laser Scanning Confocal
- White Light Interferometry
- Chromatic Aberration
- Digital Optical Microscopy
- Spectral Ellipsometry
- UV-Vis-NIR Spectroscopy

X-Ray Characterization

- X-Ray Diffraction
- X-Ray Reflectometry
- Micron-spot ED-XRF
- WDXRF
- Micro-CT
- 2D X-ray Inspection & X-ray Radiography

Chemical Analysis

- ICP-MS & LA-ICP-MS
- GC-MS
- FTIR
- Raman
- NMR (1D or 2D; solid-state and solution-state)
- EPMA

Nanoparticle Analysis

- Dynamic Light Scattering (DLS)
- Laser Diffraction Particle Size Analysis (PSA)
- Particle Zeta Potential

Material Property Characterization

- DSC
- TGA
- DMA & TMA
- Rheometry
- Surface Zeta Potential
- Nanomechanical Analysis
- Tensile-Test
- Taber Test

Surface Analysis

- X-ray Photoelectron Spectroscopy (XPS)
- Ion Scattering Spectroscopy (ISS)
- Ultraviolet Photoelectron Spectroscopy (UPS)
- ToF-SIMS (Static-SIMS)
- Dynamic-SIMS

Chris J.L. Moore, PhD

Vice President, Technology
Covalent Metrology

- Chris has over 30 years of experience in metrology techniques and the development of metrology systems
- Originally the VP of Technology for Waterloo Scientific
- Technical marketing role at Philips Analytical when WSI was purchased by Phillips
- President and CEO of Phillips Advanced Metrology Systems, Advanced Metrology Systems and finally Semilab USA
- After a stint of high technology consulting Chris moved west to join Frontier Semiconductor as VP of Marketing and Sales before joining Covalent as the Vice President of Technology and Operations
- With his generalist metrology background and expertise and significant management and leadership experience, Chris adds significant depth to the Covalent team
- Chris has a PhD in solid state physics from the University of Waterloo



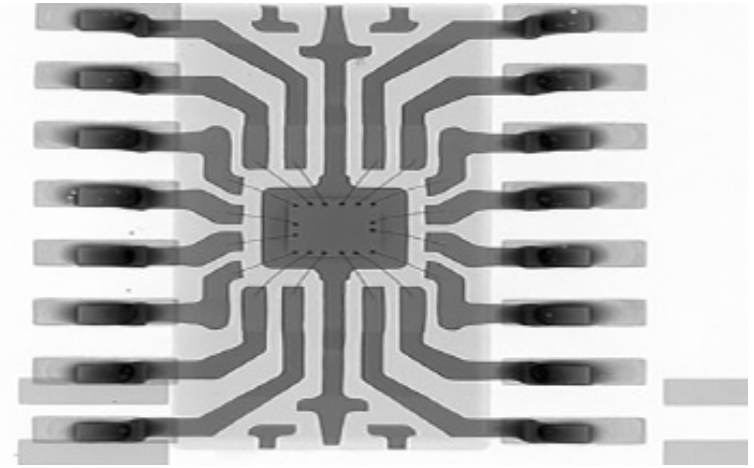
What we will discuss

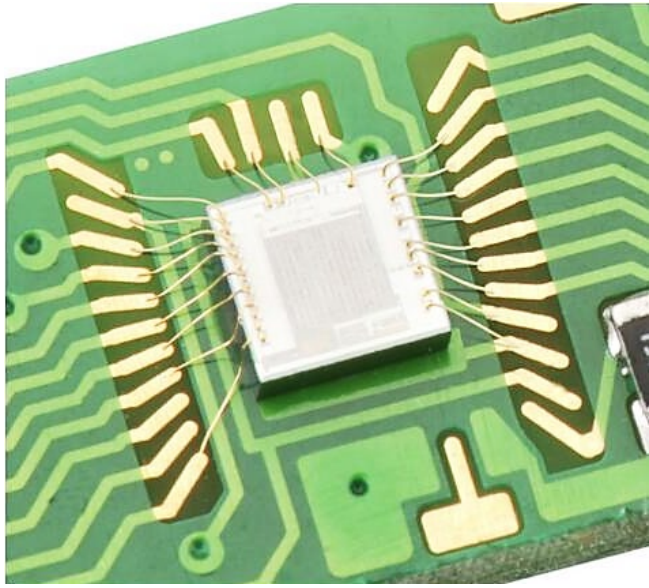
- **Formulating the puzzle**
  - Are we asking the “right” question?
  - Classes of problems (which type is yours)
  - Assumptions can be killer
- **Choosing strategy (or strategies) to solve the puzzle**
  - Design of Experiment
    - How simple can you go?
    - How can metrology help?
    - Multiple measurements and multiple parameters
    - When to cut your losses
- **Solving the puzzle**
  - The effects of Over-investing and Tunnel Vision
- **Case Study 1 – When is a Crack Not a Crack**
- **Case Study 2 – Why is My Window Getting Darker**



Formulating the Puzzle (The Question)

- Are we asking the “right” question?
  - Do we know what the **definition of success** is?
    - For **the device / material**
    - For **the measurement**
- For some, it is simple
  - Does this part match what I ordered?
    - First: validate size (dimensions) – both external and internal
    - Next: is the material correct?
  - **Supply chain issue**
- For others, it is much more complex
  - Device fails under unknown conditions
  - **Design issue**, **manufacturing issue**, **user issue**





X-ray radiograph of wire-bonded part provided by network partner Jesse Garant;
Image of wire-bonded PCB component borrowed from Rocket PCB (https://www.rocket-pcb.com/rocket-pcb-top-brand-wire-bonding-pcb-wire-for-automotive)

Common Problem Types

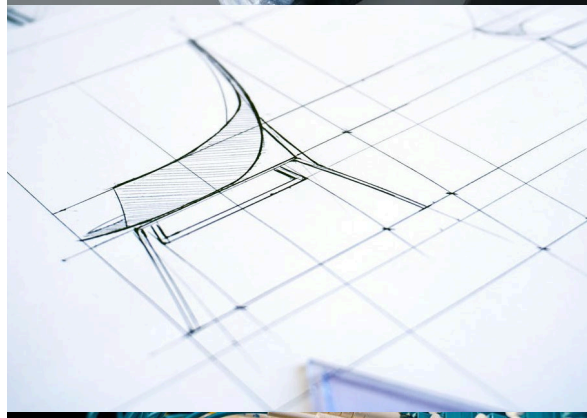
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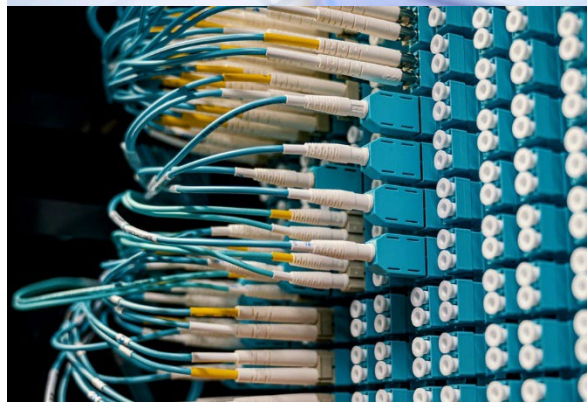
- Failure due to **Supply Chain Issues**
  - Material specified properly and did we get what we ordered
  - Part and finish tolerancing
  - Contaminated material
- Failure due to **Design Issues**
  - The switch I used cannot stand the electrical environment
    - PCB design leads to **Manufacturing Faults**
    - Know what material is wanted but cannot produce it reliably
- Failure due to **Environment or User Issues**
  - My part gets sanitized every day and my switches are still failing

Low Complexity

High Complexity







How Assumptions can Kill

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- Assume the problem is due to Corrosion
  - Spend a lot of time doing surface chemistry and surface analysis of the corrosion
  - Forget to check: is the steel is the type you expect it to be?

- Determine that a particular element or compound is causing part / device failure
  - Assume: it is being introduced as part of your manufacturing process
  - Later find the plastic you are using was contaminated

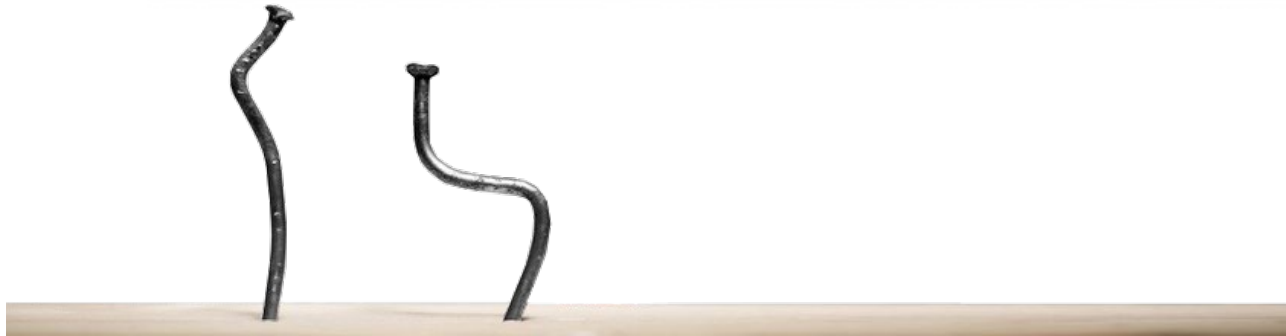
- **List your assumptions, then check and verify** where you can

Choosing the Way

> " If you have a hammer, everything is a nail "

- Often the troubleshooting strategy is determined by:
  - What you have
  - What you have done in the past
  - What others told you they did
  - No time left to do anything else





Leverage Your Team and Your Partners

- Leverage Your Team and Your Partners
- …**NOT**

What Normally Happens?

1. Engineers at the company discuss a problem
2. Hypothesize root cause
3. How could we measure this?
4. Let's try AFM!
5. Call to metrology lab – Ask:
   - Do you provide AFM services?
   - If so, how much and what is the turnaround time?

- **This process fails**
- Consequence is often confusion, delays, wasted time and wasted money

What Went Wrong?

- The people and process that formulated the question **did not include any experts in Metrology and Characterization**
- If any expert was eventually consulted, it was likely an AFM expert discussing AFM
  - Less expertise in other analytical options

Is Metrology or Materials Characterization your core competence?

Leverage Your Team and Partners

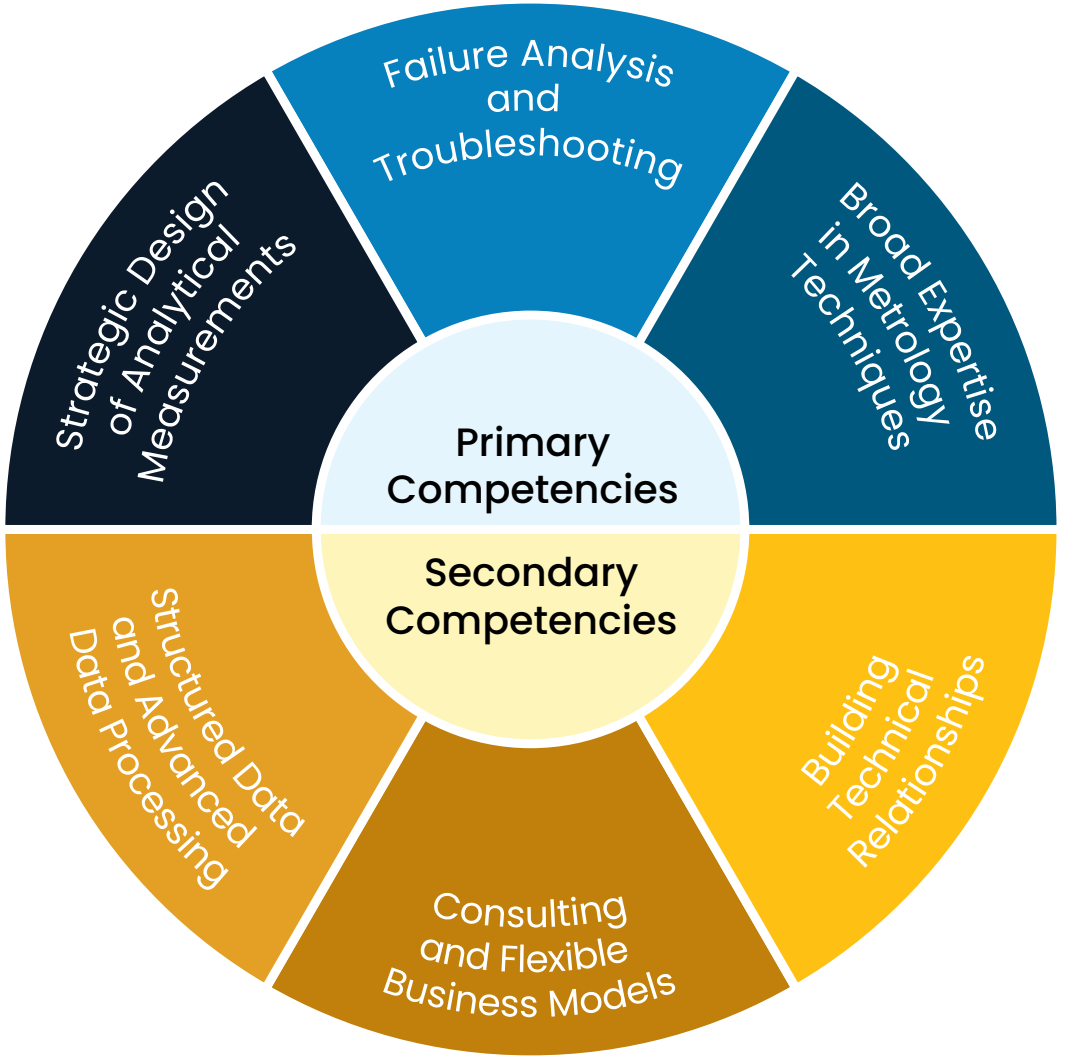
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	AFM	Stylus Profilometry	FRT (CDP)	VK (LSCM)	WLI	3D Patterned Light	SEM	S/TEM
Field of View	200nm – 70µm	N / A	160µm – 800µm	100µm – 1mm	5µm – 200mm	4mm – 24mm	1µm – 2mm	2nm – 10 um
Vertical Precision	Å	Nm	Nm	nm	Å	3-5 µm	nm	Å
Max Sample Diameter	300 mm	200 mm	200 mm	Flexible	Flexible	Flexible	200 mm	Appx 100 µm
Best for Material Types	Smooth, Hard	Smooth, Hard	Opaque, No Steep Slopes	No Steep Slopes	Opaque	Opaque, No Steep Slopes	Conductive	Nano-scale Features
Applications								
Non-destructive			●	●	●	●		
X-Section Imaging	●		●	●		●	●	●
Flexible-Angle Imaging			◐	●		◐	●	
1D Height Line-scan	●	●	●	●	●	●		
2D Height Map	●		●	●	●	●		
3D Profile	●		●	●	●	●		
3D CAD Model						●		
Quantitative Dimensions	●	◐		●			●	●
Element Analysis							●	●
Nanomechanical Analysis	●							

Leverage Your Team and Partners

- Metrology / Characterization is an **enabling competence** for most companies
  - For companies like Covalent it is their **core competence**

- The better we understand the problem the more we can help
  - Give you **choices**
  - Access to breadth and depth of core experience and expertise



Choosing the Way (Design of Experiment)

Customers
(Engineers Solving Problems)

Define the Problem,
Recommend Strategy, Assign

Data Generation
(Measuring, Imaging Samples)



Covalent Lab

- 80 – 90 % of business today
- 24,000ft^2 in Sunnyvale
- 40+ cutting-edge instruments

Universities

- World class equipment but difficult to operationalize
- Forged strategic relationship with University of Oregon

Private Labs

- 11 partners with arranged discounts

Validate Quality, Interpret Results,
Recommend Next Steps

Choosing the Way

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01 Design of Experiments

02 Processing & Fabrication

03 Measurement & Characterization

04 Analysis of the Data



Choosing the Way (Design of Experiment)

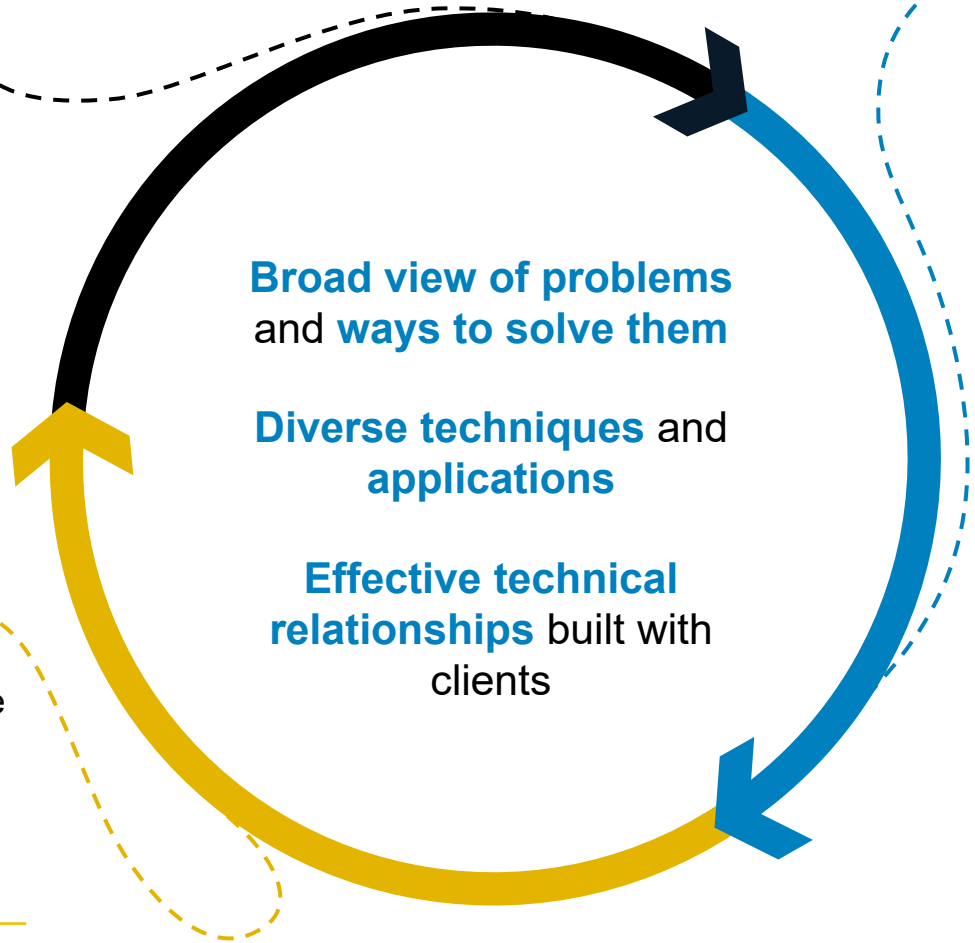
Analytical Services

Consulting

- Lab-to-fab assistance
- Metrology techniques / strategies
- Your partner for help with key projects

Retained Relationships

- Take responsibility for entire metrology & characterization function
- Embedded Covalent team members
- Customer lab management



Flexible Services

- Relentless focus on excellence and cost-effectiveness
- Diversified service options
- New Business Models

Covalent Metrology is growing to become a preferred partner for all metrology & characterization needs

Simplify the Problem

- Real samples and real problems are fiendishly difficult
- Most people follow one of three strategies

1. Build the complex device by adding **simple layers/structures**
   - Apply what you learn from the simple structure to help your understanding of the complex one
   - **Pros:** powerful, simplifies and isolates parts of problem
   - **Cons:** time consuming and expensive; and you assume you know what counts



Focus the Metrology

2. Find a metrology solution (or a series of solutions) which measures the parameter(s) of interest which is not susceptible to the complexity
   - Try to keep the sample preparation as simple as possible

For example

One can measure trace metals in a plastic using WDXRF

OR

You can put the sample through a digestion process and then use ICP techniques

Which is better depends on the customer need

- Will discuss more in Case Study 1



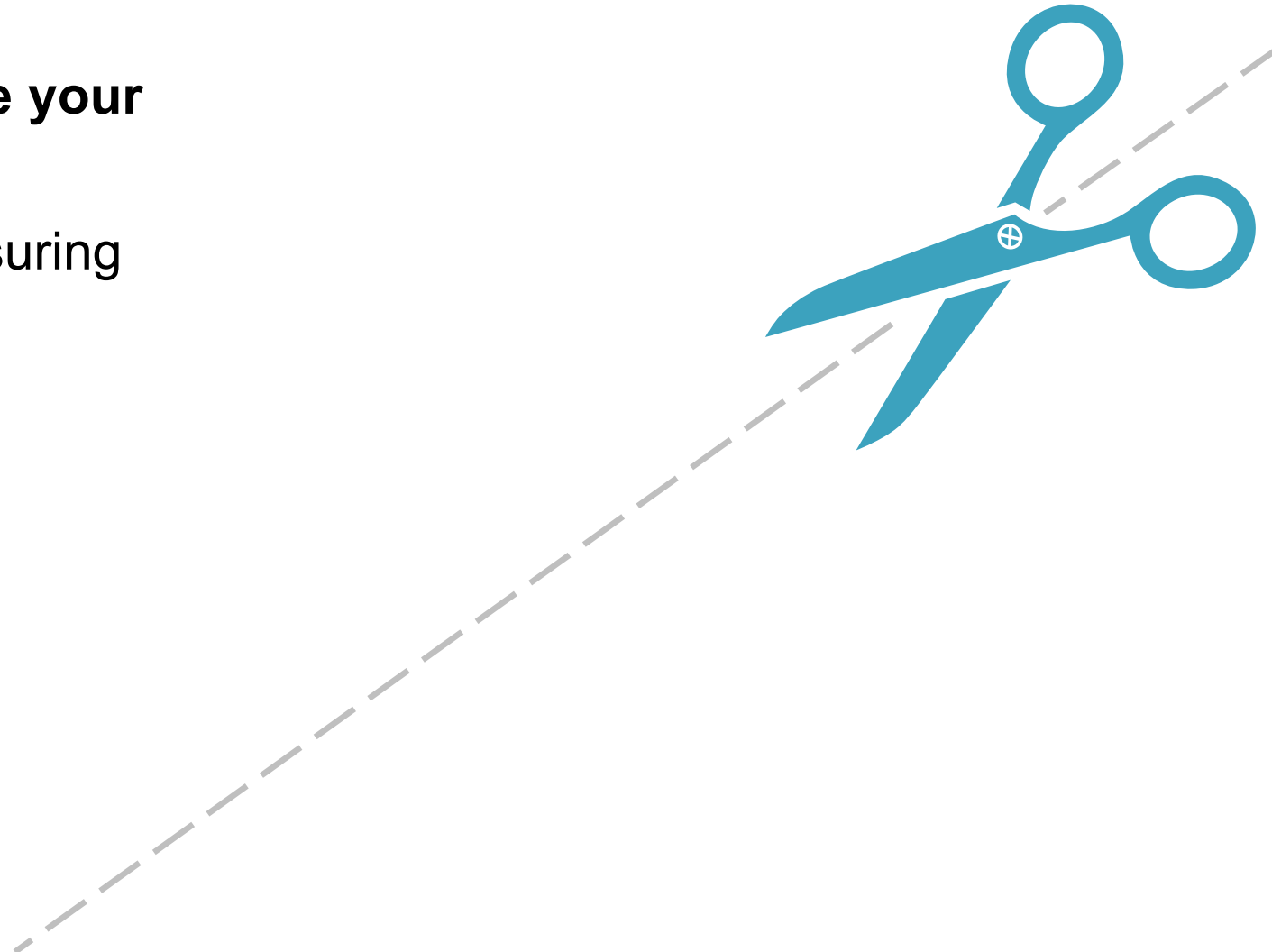
Multiple Measurements for Multiple Parameters

- In real systems there is often a need for multiple measurements to isolate the parameters of interest
- i.e.
  - Combination of XRD and XRF lets you determine structure knowing the basic chemistry
  - Combination of TEM and XRR gives you better modelling capability
- Many metrology techniques use models (implicit or explicit) to produce measurements
- **You need to understand how the measurement is made in order to know if the data is real**

Cut Your Losses

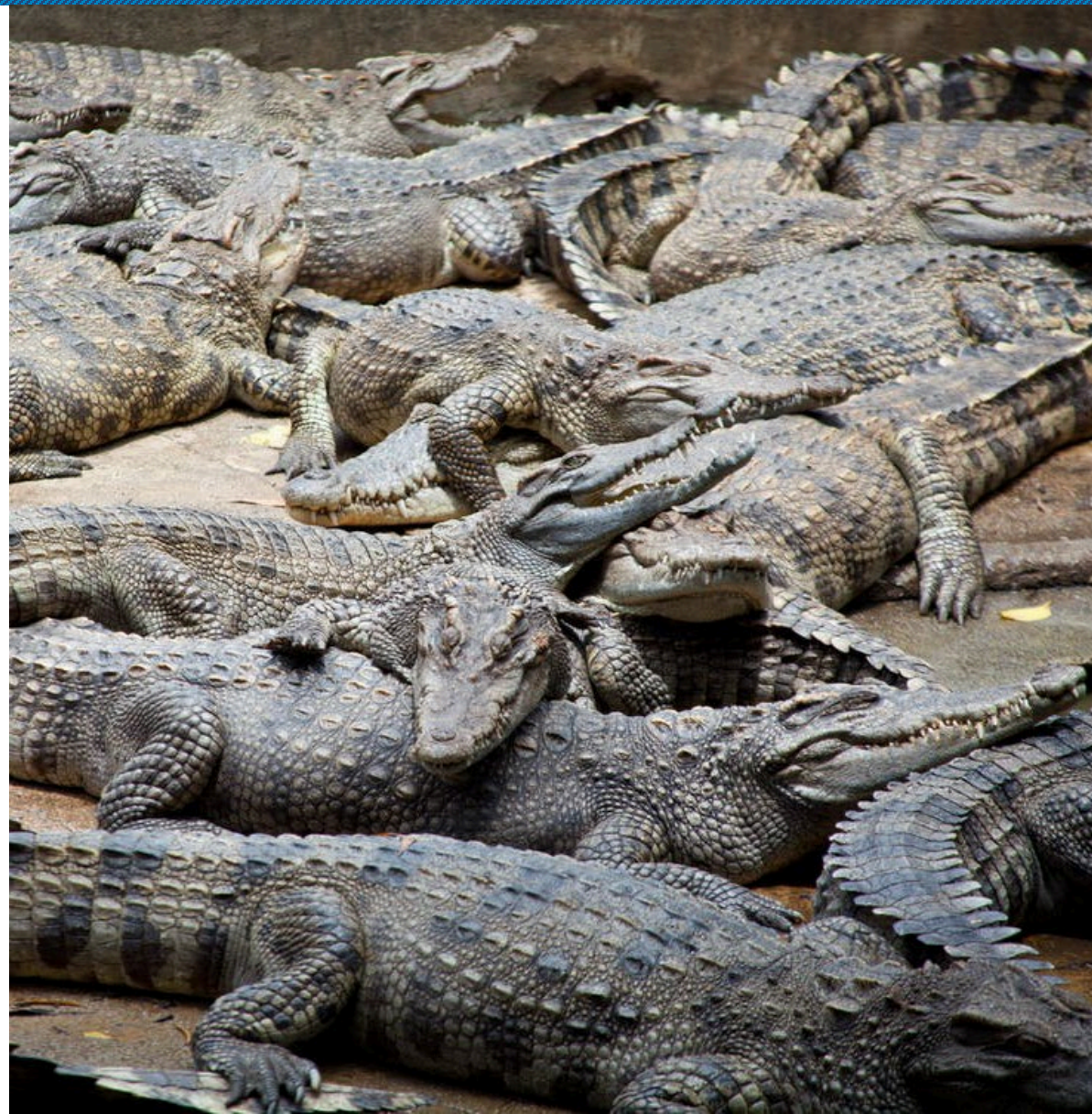
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- When data does not support your hypothesis, you can:
  - Re-examine the data and **change your hypothesis**
  - Ignore the results and keep measuring
  - **Change the measurement**
  - **Get help by engaging a partner**



Over-investing and Tunnel Vision

- Just because it was your idea does not make it right
  - Over-investing can lead to dead ends and costs time
- Are you ***beating alligators*** or ***draining the swamp***?
  - Did you list all possible assumptions and explanations for the problem?
  - Did you check all items on the list?



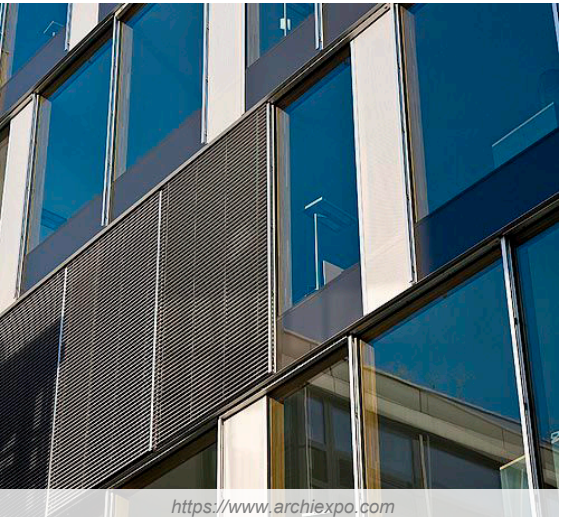
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Case Studies

Case Study 1 – When is a Crack not a Crack

- Development of a **residential electro-chromic window system**
  - Transmission of light in the visible region is managed by electronic controller
  - Multiple-layer, multiple-technology solution; moving to mass production
  - Product development transitioning to production, focusing on **consistency** and **quality**

- Client and Covalent have developed a working partnership where Covalent team members became **part of the client's metrology team and strategy**

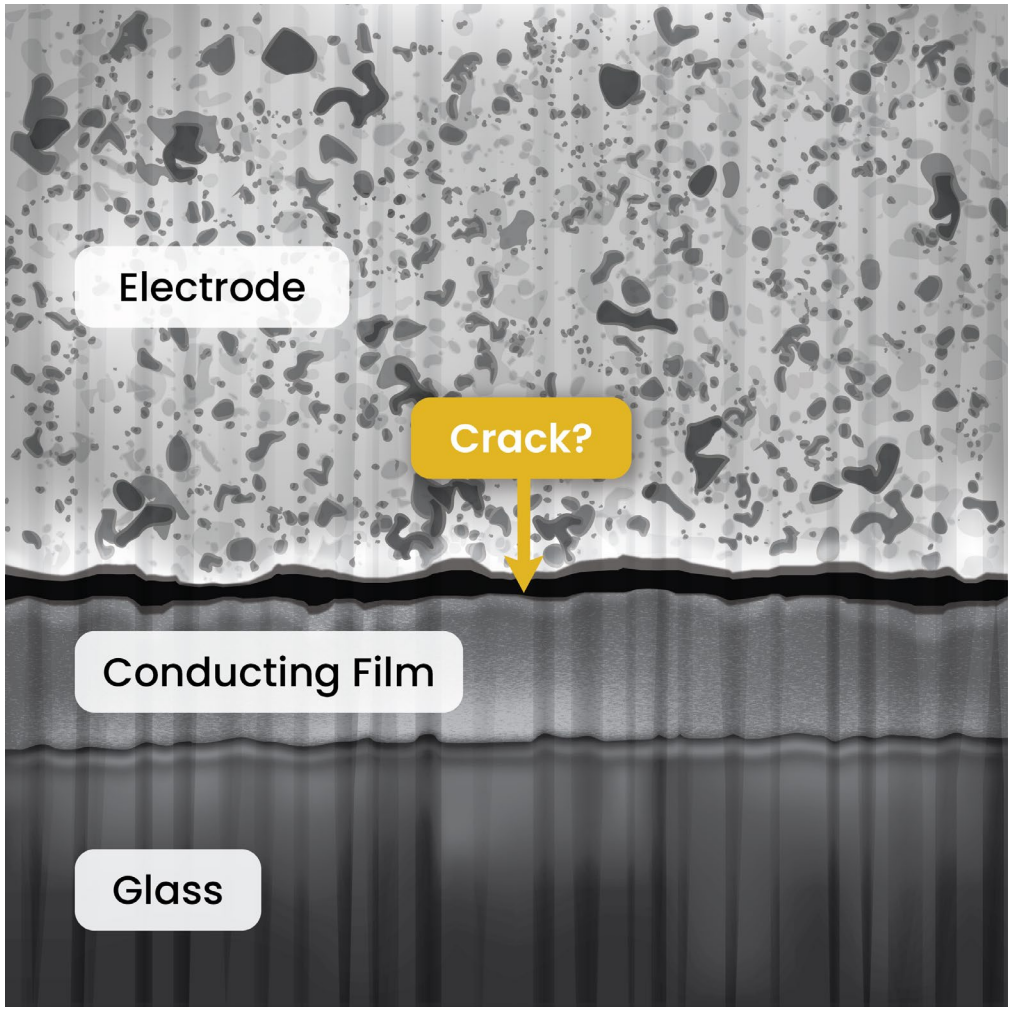

https://www.archiexpo.com


https://5.imimg.com/data5/BY/EH/FP/SELLER-8533391/switchable-smart-glass-film-500x500.jpeg


https://www.sageglass.com/en

Case Study 1 – When is a Crack not a Crack

- Basic structure can be thought of as **two electrodes sandwiching an electrolyte**
  - Under certain conditions, failures were seen which were thought to be due to delamination (i.e. see drawing to the right)
  - **First Thoughts:**
    - Cross-section the device and image it
    - Image a good one and a failing one, then compare



Artist Drawing - Not a Real Sample

Case Study 1: The Complication (Remember Assumptions)

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- Cracks were indeed seen once the samples were cross-sectioned
  - Determined that under certain manufacturing parameters crack could be caused but more cracking than expected
  - **However: noticed that cracking seen more prevalent near the FIB cut**

- Was the crack real or caused by the cutting of the sample?

- Is this the crack a **failure mechanism** or the **result of the measurement?**

- **Either way need to have an inline quality control measurement**

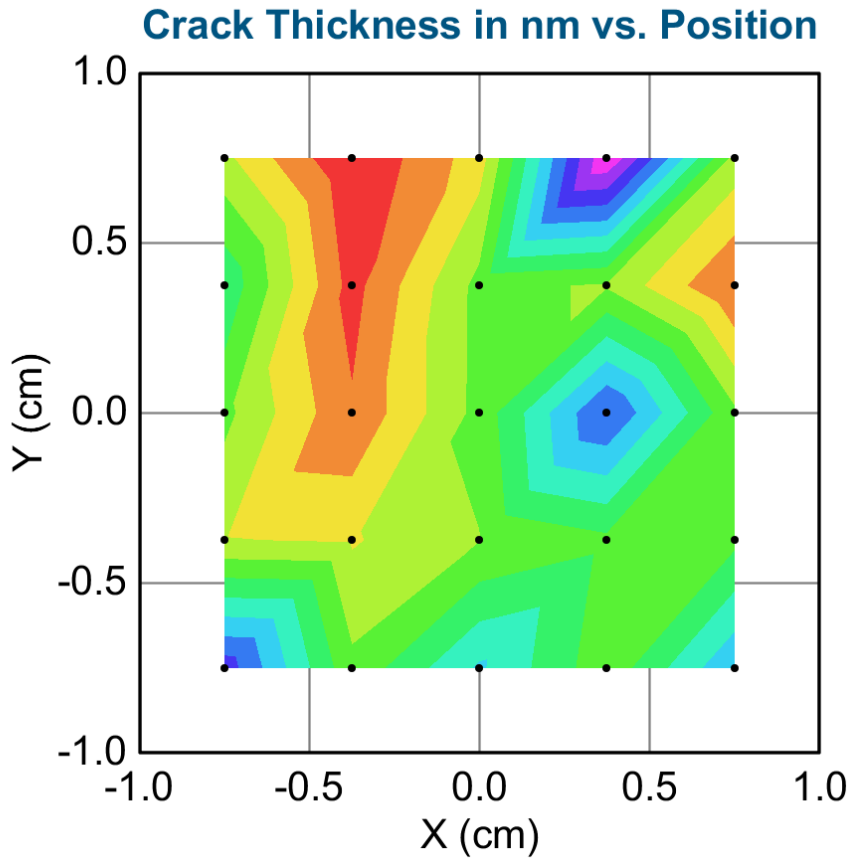
Case Study 1 – When is a Crack not a Crack

What technique and why

- **Scanning Acoustic Microscopy**
  - Not a good environment (done in water)
  - At best will tell you if there is delamination
  - Not amenable to inline use

- **Spectroscopic Ellipsometry**
  - System is transparent (it is a window)
  - But analysis is very complicated
  - Simplify the modelling (lumped parameters)
  - If delamination is there, index change can be easily measured
  - If needed: could be used as an inline monitor during production

Spectroscopic Ellipsometry



Case Study 1: Why 1 + 1 > 2

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Client:

- ✓ Understands what is in their window
- ✓ Understands the processes they go through to manufacture it
- ✓ Hypothesizes what failure mechanism could be

+

Covalent:

- ✓ Understands metrology applications
- ✓ Provides expertise across wide range of techniques/technology/experience
- ✓ Has the analytical equipment and the manpower

- Cross-sectioning / Destructive Physical Analysis is a standard method for failure analysis
  - Cut it, FIB it, break it, and so on
  - Can debate pros and cons of each approach
  - All available options
- **Spectroscopic Ellipsometry** is not so obvious until you choose it

System and Process Expertise + **Metrology and Characterization Expertise**
= **Effective Quality Control Method**

Case Study 2 – Why is my Window Getting Darker

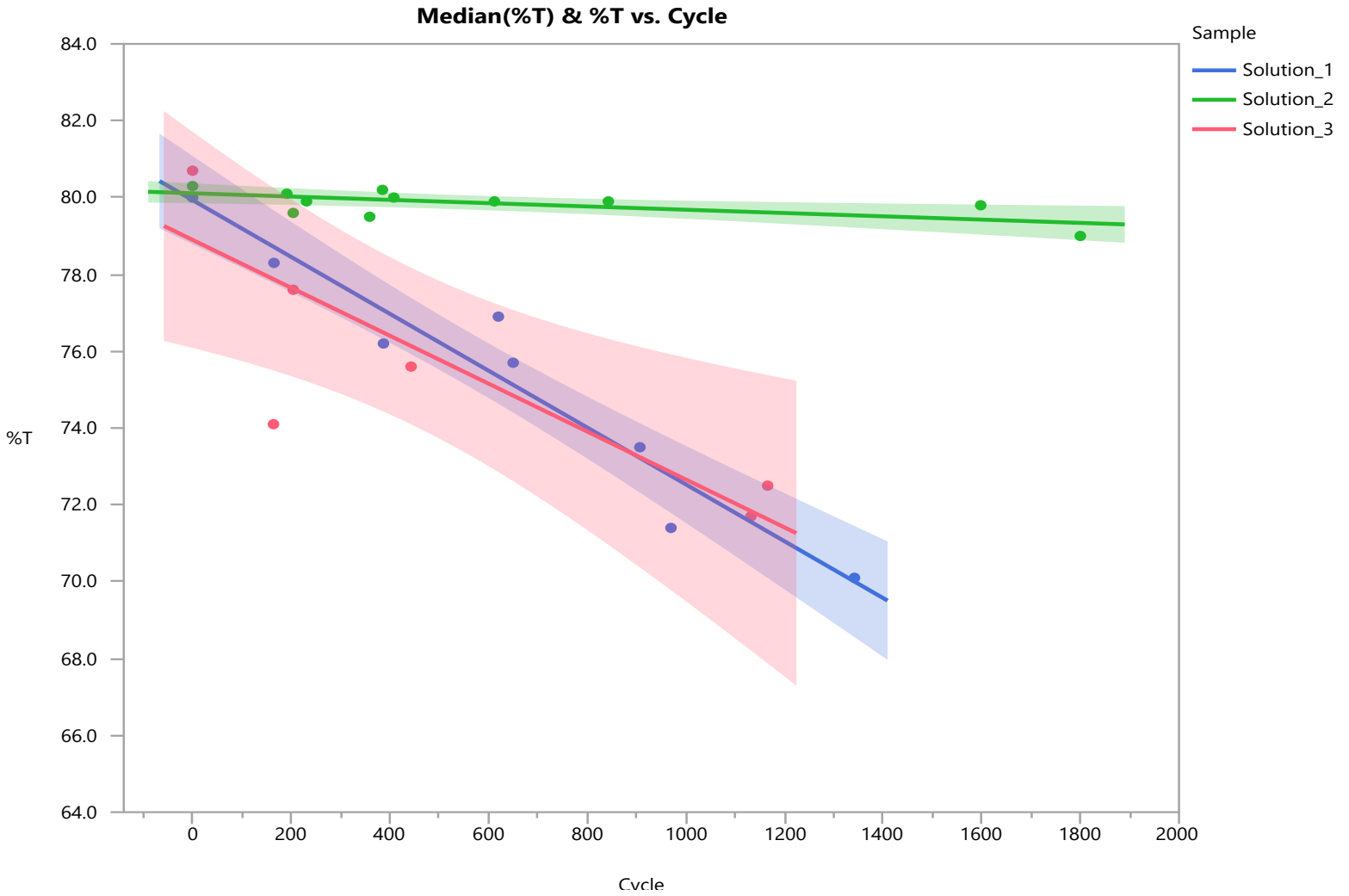
- Similar material system to Case Study 1: **residential, electro-chromic glass**
- During early development, after repeated cycling it was found that the window was “yellowing”

- **First thought:** UV yellowing like that seen in older safety glass
  - Could the effect be measured?
  - Transmission was most important property to measure
    - Suggested UV-VIS measurement as a function of cycles
    - Measurement showed *decrease in transmission*
    - But *no UV was getting to device itself*
  - **Which element of the device was causing it?**
    1. Glass
    2. Electrode
    3. Electrolyte….
  - **Investigate with the client alternative paths / materials**



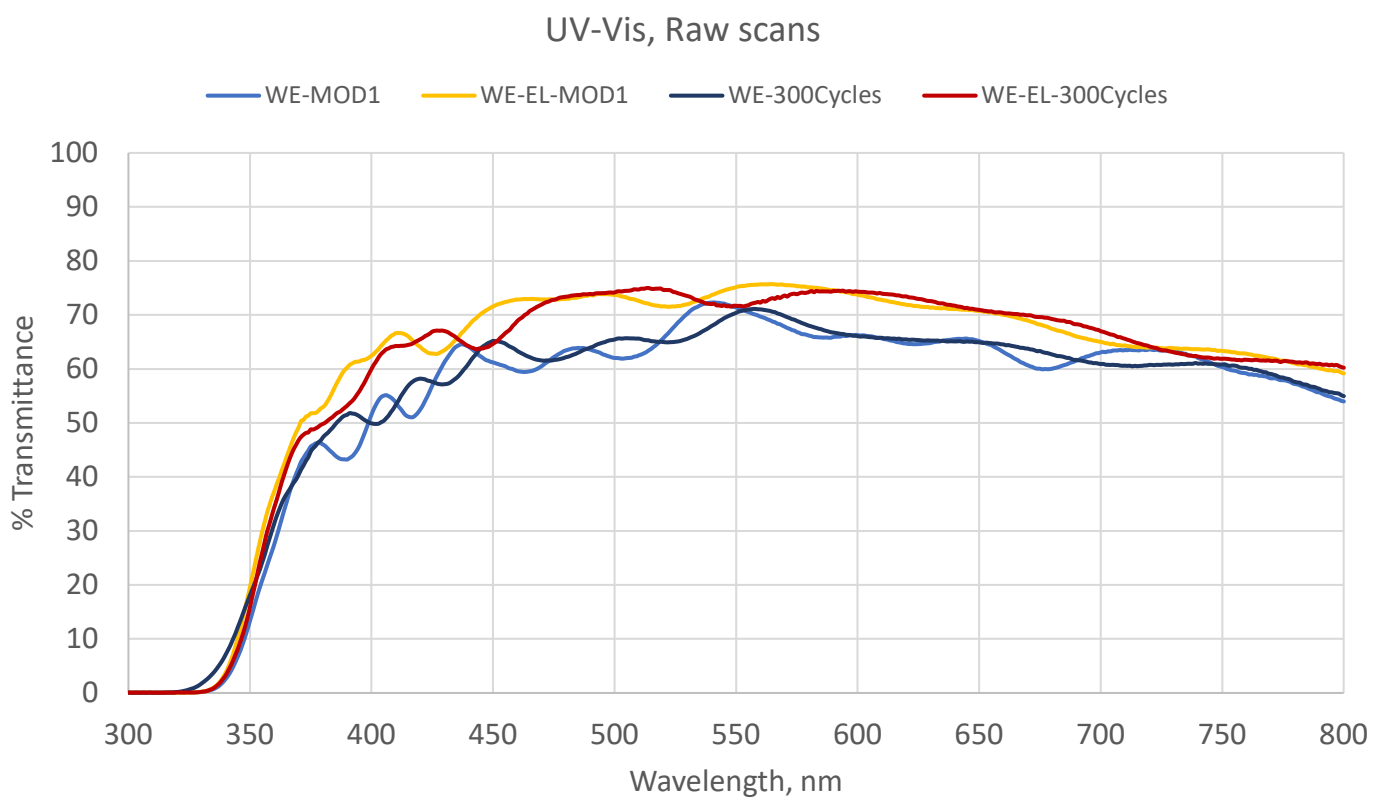
Example UV-changed glass tint borrowed from *https://www.peachridgeglass.com/*

Case Study 2 – Why is my Window Getting Darker



- Early studies showed an issue with long term performance
- With the client developed a metrology strategy and DOE
- Client developed new alternatives to eliminate / minimize the effect

Case Study 2 – Why is my Window Getting Darker



- Determination made that **UV-VIS spectroscopy** made a good development metrology method
- Used to measure the behavior of different electrolyte formulations over time
- Could also be used to measure the complete structure
- In order to fix a problem, you need to be able to “see” it

Case Study 2: Why 1 + 1 > 2

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Client

- ✓ Did the original QC testing and cycling
- ✓ Made the measurements
- ✓ Worked to find alternative solutions

+

Covalent

- ✓ Advised on measurement methods
- ✓ Guided isolation of failure cause
- ✓ Helped guide troubleshooting next steps

Discuss Together

- ✓ Validated part failure
- ✓ Generated and discarded hypotheses
- ✓ Strategized effective QC method and measurement

- The discussion involved a number of different metrology measurements and data interpretation
- Covalent focused on data interpretation and optical expertise so the client could focus on developing solutions to the problem

Deep Understanding of Part and Problem + **Experience in Metrology Troubleshooting**
= **Faster, Cost-Effective Solution**

Our Clients Thoughts

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" Partnering with Covalent for analytical and metrology services brought additional expertise to our in-house team that enabled us to answer key questions, resolve issues, and accelerate time to market "

- Client CTO

Covalent as a Metrology Partner

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Nanoparticle Analysis

- Dynamic Light Scattering (DLS)
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Surface Analysis

- X-ray Photoelectron Spectroscopy (XPS)
- Ion Scattering Spectroscopy (ISS)
- Ultraviolet Photoelectron Spectroscopy (UPS)
- ToF-SIMS (Static-SIMS)
- Dynamic-SIMS

Some Final Thoughts

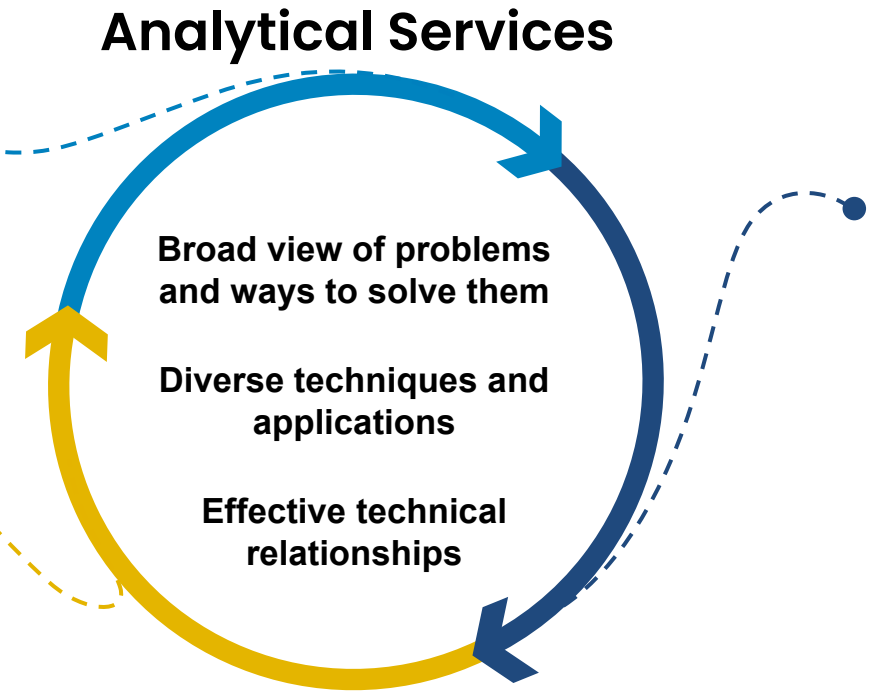
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Consulting

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- Metrology techniques / strategies
- Your partner for help for key projects

Flexible Services

- Relentless focus on excellence and cost-effectiveness
- Diversified service options
- New Business Models



Retained Relationships

- Take responsibility for entire metrology & characterization function
- Embedded Covalent team members
- Customer lab management

- Time to market often determines winners and losers
  - For most metrology is an enabler not their core business
  - Buying equipment and finding the right people takes time (and time is money)
- 10 years ago: people built their own server farms
- Now you go to Amazon or Google or Microsoft and they become a partner in your solution

Why Outsource?

They have **experience** and **scale.**

They can do the work **better, cheaper** and can **provide faster solutions**

Summary

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1. Define the Problem

- What is success
- What are the assumptions

2. Choose your Solution Strategy

- Single or multiple metrology techniques
- Does your DOE fit time and cost
- Inhouse or partner or hybrid

3. Solve the Puzzle

- Be data driven
- Avoid tunnel vision
- Leverage the resources available
- Adapt your approach as needed

Finally, a Personal Note

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- In September of 2022 I will have been doing metrology problems for 50 years
  - Why keep going
  - Helping our clients solve problems
    - Keeps me interested and engaged
    - Allows me to use our expertise to reduce their workload
    - Helps them make the world a better place

Coming Up Next…

COVALENT METROLOGY

OPTIMIZING MATERIALS WITH THERMOGRAVIMETRIC ANALYSIS (TGA) AND DIFFERENTIAL SCANNING CALORIMETRY (DSC)

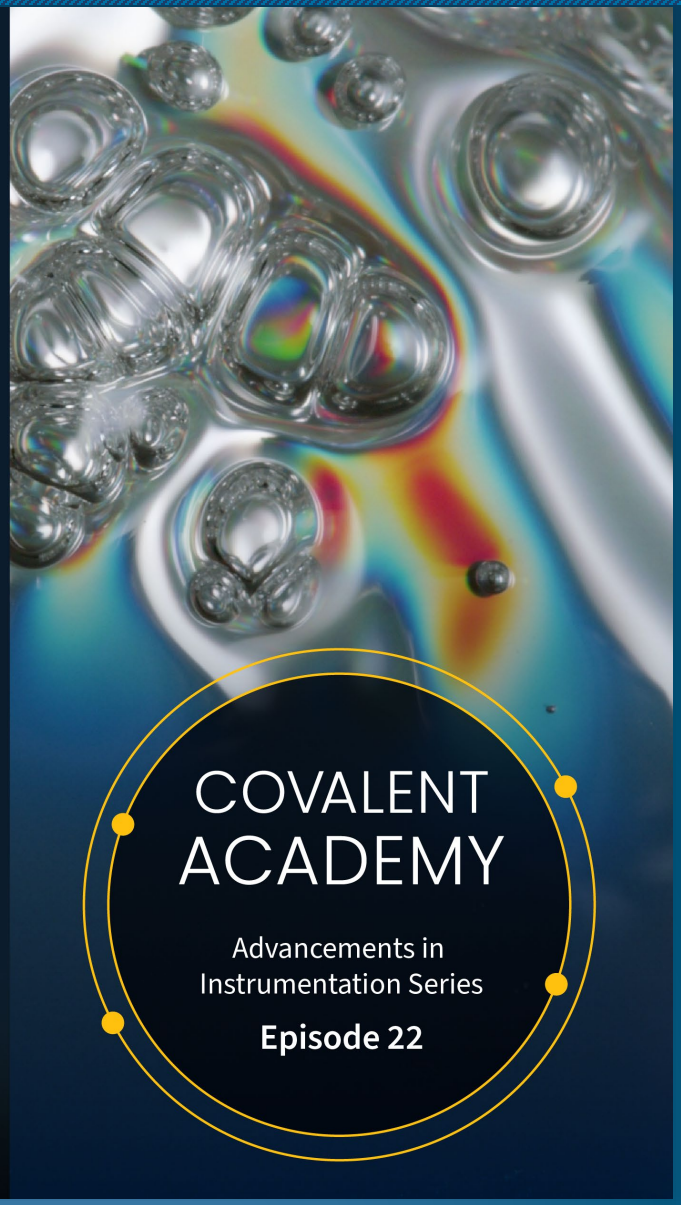
SPEAKER:

Parth N. Vakil, PhD
Applications Scientist,
TA Instruments

May 6, 2021 | 11AM PT

TA Instruments

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Opportunity: Free 30min Discovery Consultation!

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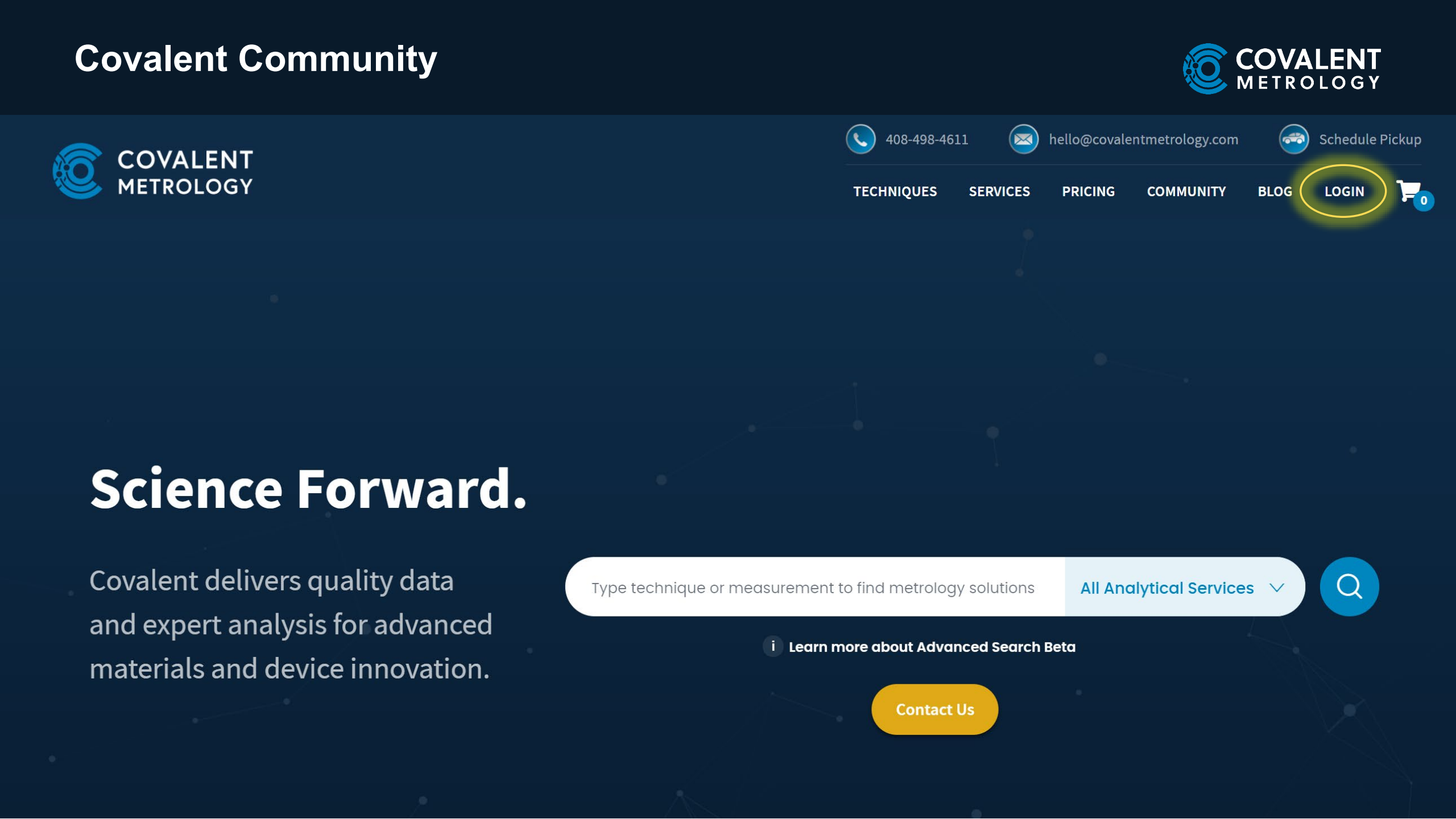
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Consulting Solutions and Analytical Services?

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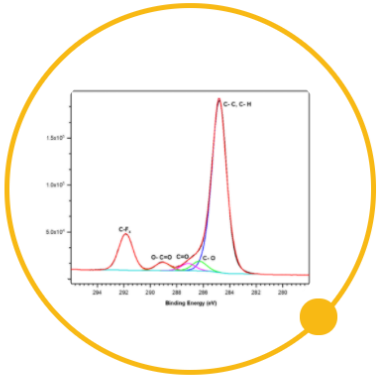
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Access Covalent Portals

Customer Access to Data & Community Content



The DATA PORTAL is used by Customers and Lab Partners for uploading and downloading data. It requires two-factor authentication and advanced password protection. Data Portal users have complete access through their home page on the portal to all Community content, and do not require a separate Community account.

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Community Content Access for All Other Users



The COVALENT COMMUNITY PORTAL requires password entry. It contains webinar and other metrology and characterization-related content that we believe would be useful and educational for the materials science innovation community. It does not provide access to any customer data and should only be used by individuals that are not Covalent customers or lab partners.

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Q & A Session

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Thank you