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2025 Users Conference

Manufacturing Data Analytics

for Fab and Advanced Packaging

Jon Holt

December 4, 2025

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04.

UC SANTA BARBARA

Customer Presentation

UCSB

Data Analytics for University Nanofabs: Enabling Innovations and Facilitating Lab-to-Fab Technology Transfer

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https://www.nanotech.ucsb.edu/
https://wiki.nanotech.ucsb.edu/

UC SANTA BARBARA

Mission: To Serve UCSB and greater community in their micro-nanofabrication research and development endeavors. To enable both the highest caliber of research and to enable impact beyond the university walls.

Provide exceptional physical resources and professional technical expertise/support to UCSB and external facility users

Provide easy access for external industrial, small company users

UCSB Nanofab Overview

UCSB

What?

The UCSB Nanofab is an **advanced nanofabrication <u>user</u> facility**.

- **Open access**: Users are internal (UCSB) and external (other universities, government, and industry) : Over 25 years
- Facility houses **~$60M of equipment**
- Primarily **Compound Semiconductor** (GaAs, InP, GaN, GaSb, …)
- **Expert Staff Support**
    - 5 PhD level, 2 MS, 1 BS level technical process support staff
    - 9 Professional Systems engineering and facility staff, 2 Tech Support, 1 dedicated IT

Why?

To support innovation and product development

- User base is **~540 annual users** and **>40% of these users are from industry**
- **~6000 monthly hours** billed. **~50% of hours are industrial use**.
- 75 local companies have used us since 2006.

How?

The UCSB Nanofab charges user fees to support its operating budget.

- Rate structure set to cover all costs and facilitate improvements.
- **Tiered Rate structure**: Industry access at $151/hr. UC Academic at $40.50/hr.
- Has allowed us to run in black without subsidy for over 10 years.
    - Large industrial (small company) user base AND vibrant research program
    - Strong entrepreneurial culture with institutional support

UCSB Nanofab Impact at a Glance

UCSB

Maps of UCSB Nanofab users

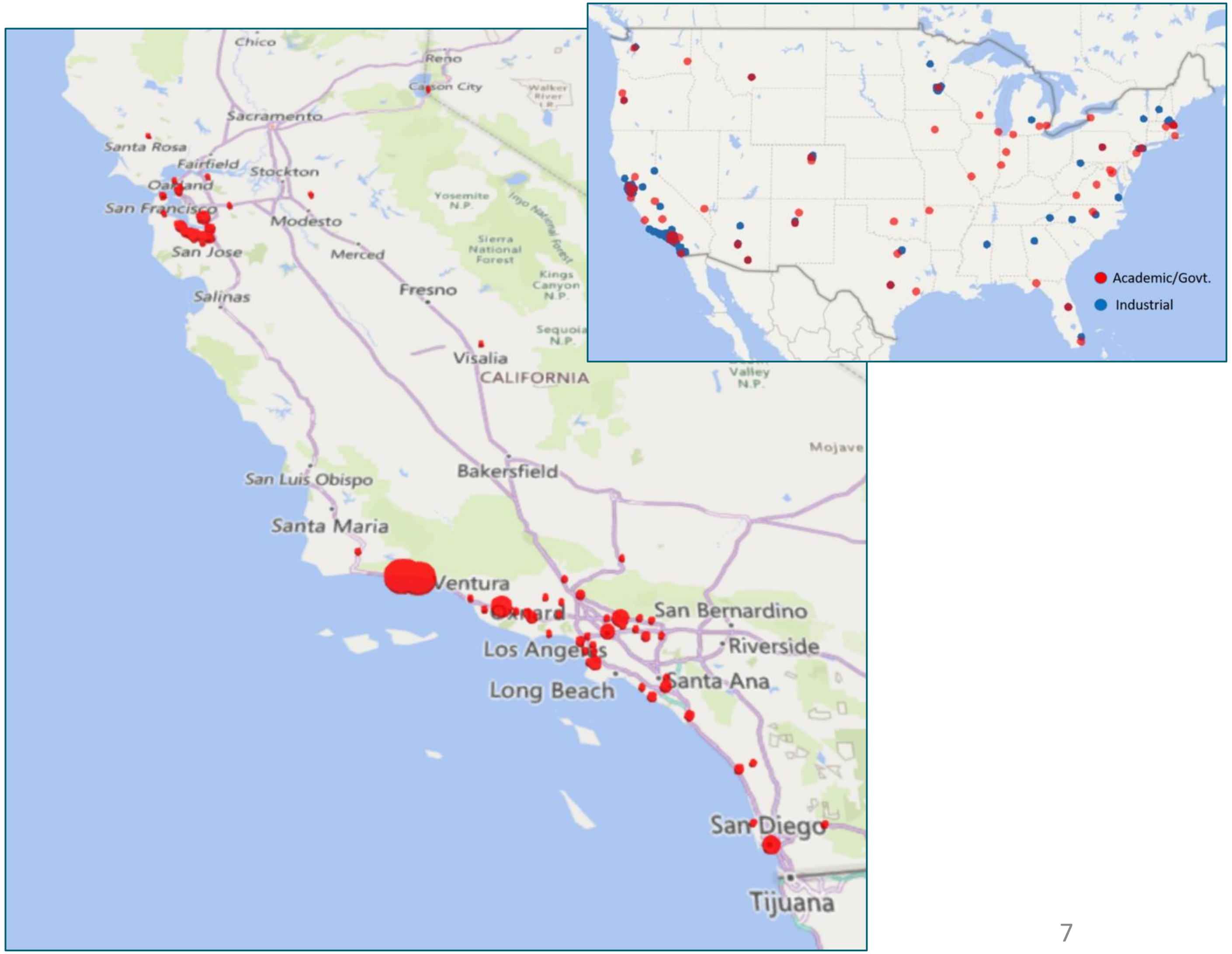
UCSB Nanofab by the Numbers (since 2006)

- ***State Impact***: UCSB Nanofab has been accessed by **over 230 California companies**

- ***National Impact***: **309 companies nationwide** have accessed the facility, and of these, **240 are small companies**

- **75 companies are local** (Goleta and Santa Barbara)
  - 35 of these companies are local start-ups and 31 are led by UCSB faculty and/or graduates

- **83 US academic institutions** served

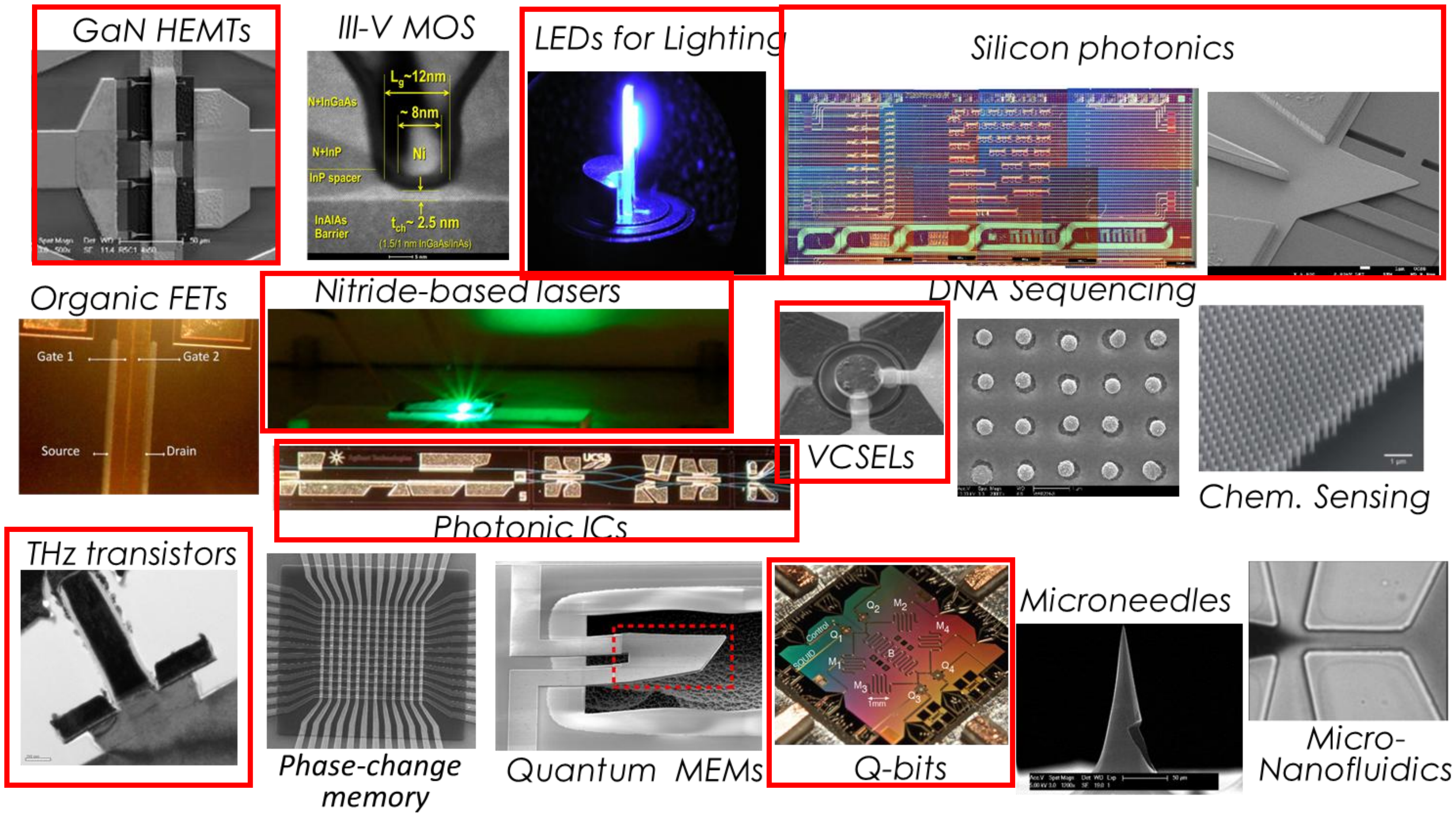


Sampling of Research Areas Leveraging UCSB Nanofab

UCSB

- Facility and capabilities support efforts across science and engineering including:
  - Electronics
  - Photonics
  - MEMs
  - Microfluidics
  - Materials
  - Physics
  - Chemistry
  - Biology
  - Quantum
- Mixed materials and use
- Strong emphases on:
  - Compound semiconductors including GaAs, InP, GaN, GaSb, and related compounds
  - Heterogeneous integration of compound semiconductors on other platforms including silicon

*Note: Heterogeneous integration includes flip-chip integration, wafer bonding, micro-transfer printing, and direct heteroepitaxy



Recent Industrial User and Commercialization Successes

UCSB

SAFRAN

ATTOLLO Engineering

- Imagers and range finders for defense and aerospace
- Processes developed at UCSB then transferred to production
- Acquired by Safran in 2025
- ~80 employees

KYOCERA SLDLASER

- Soraa and then SLD Laser develop LED and laser products for lighting, displays
- Founded by Nobel Laureate Shuji Nakamura, Steven DenBaars, James Raring (UCSB graduates and faculty)
- Acquired by Kyocera and >200 employees

Aeluma™

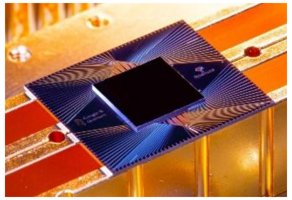
Autonomous Vehicles

Industrial Automation and Machine vision

Robots

- Scalable, cost-effective sensors for automotive and industrial LiDAR
- Founders are UCSB graduates and faculty
- Company went public in 2021, Nasdaq in 2025

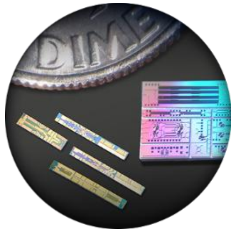
Google AI



- Quantum computing technology spun out of UCSB physics to Google
- Fabrication development at UCSB Nanofab – Sycamore Chip
- Established labs in Goleta
- >150 employees

FREEDOM PHOTONICS A LUMINAR COMPANY

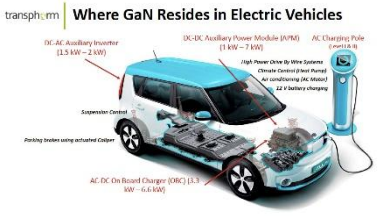
LUMINAR



- Lasers and photonic integrated circuits for communications and sensing
- Processes developed at UCSB and transferred to foundry
- Founders are UCSB graduates
- Company acquired by Luminar in 2022

transphorm

RENESAS

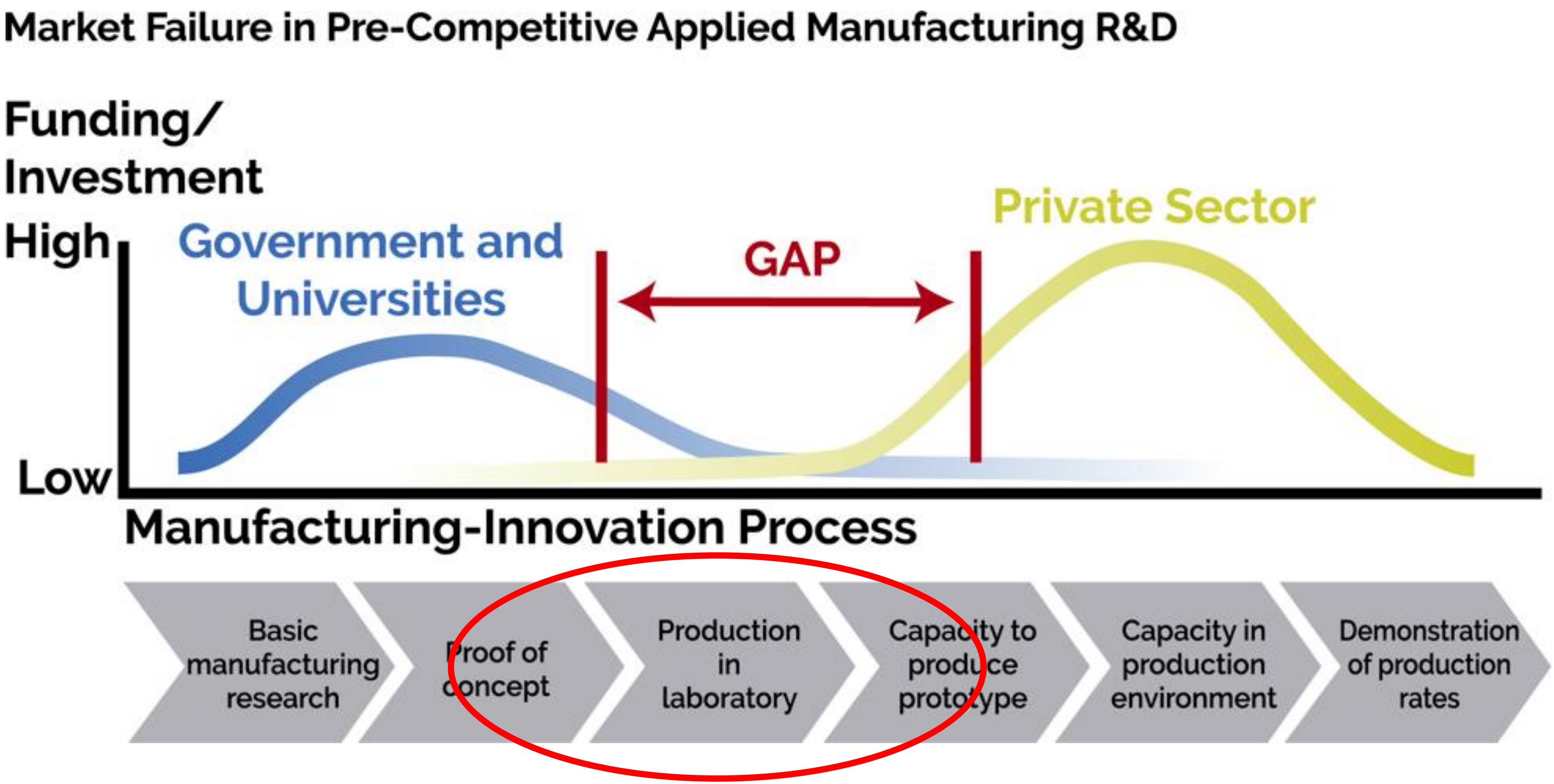


- GaN power electronics and RF devices
- Founded by UCSB graduates and faculty (Umesh Mishra – now the Dean)
- Processes developed at UCSB and transferred to production
- Company went public in 2020, Acquired by Renesas in 2024

- Ultra-low noise crystalline mirrors for spectroscopy and sensing applications
- Processes developed at UCSB Nanofab
- Founded by UCSB graduate
- Acquired by Thorlabs

ME Commons – Reduce Lab to Fab transition time (DoW)

UCSB



Improve User Outcomes in Nanofab (Lab) to reduce proof of concept times.

Improve reproducibility in Nanofab to enable production in laboratory to reduce risks of investment/transfer to fab

Explore machine matching for more efficient process transfer between Lab and Fab

Typical university R&D nanofabrication facilities

DREAMS
Defense Ready Electronics and Microdevices Superhub

- **Rely on user-reported errors. Often Reactive – Not Proactive**
  - Systems go down unexpectedly – failed runs
- **Minimal qualification/calibration runs on systems**.
  - Outcomes not always stable for multiple processes – Add interns for more data.
- **Not enough staff to increase number and frequency of calibrations**.
  - Simply checking MFCs, leak rates, etc. is not enough.
- **Huge mix of materials and processes within same systems**.
  - Run many different materials within short periods of time.
  - Effects of previous runs not always understood.
  - High risk environment – tradeoffs – research vs. stability
- **Redundancy of systems for process isolation is too expensive**.
  - Even non production tools have significant costs. Money always tight at University.
- **Hundreds of different people touch, use, program systems**.
  - Not a small team of operators.
  - Lots of young users. Human Errors are abundant – even with SOPs

Improving Outcomes and Reproducibility with PDF Solutions

With Fatt Foong, Noah Dutra, Vraj Mehalana
PDF support (Jackie, Weldon, Aruga, Samuel, Rock)

UCSB

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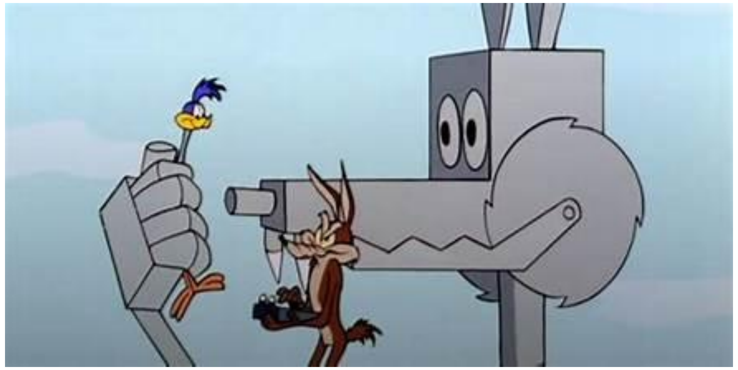
Goal: Use machine data analysis to bring active monitoring and control to the lab



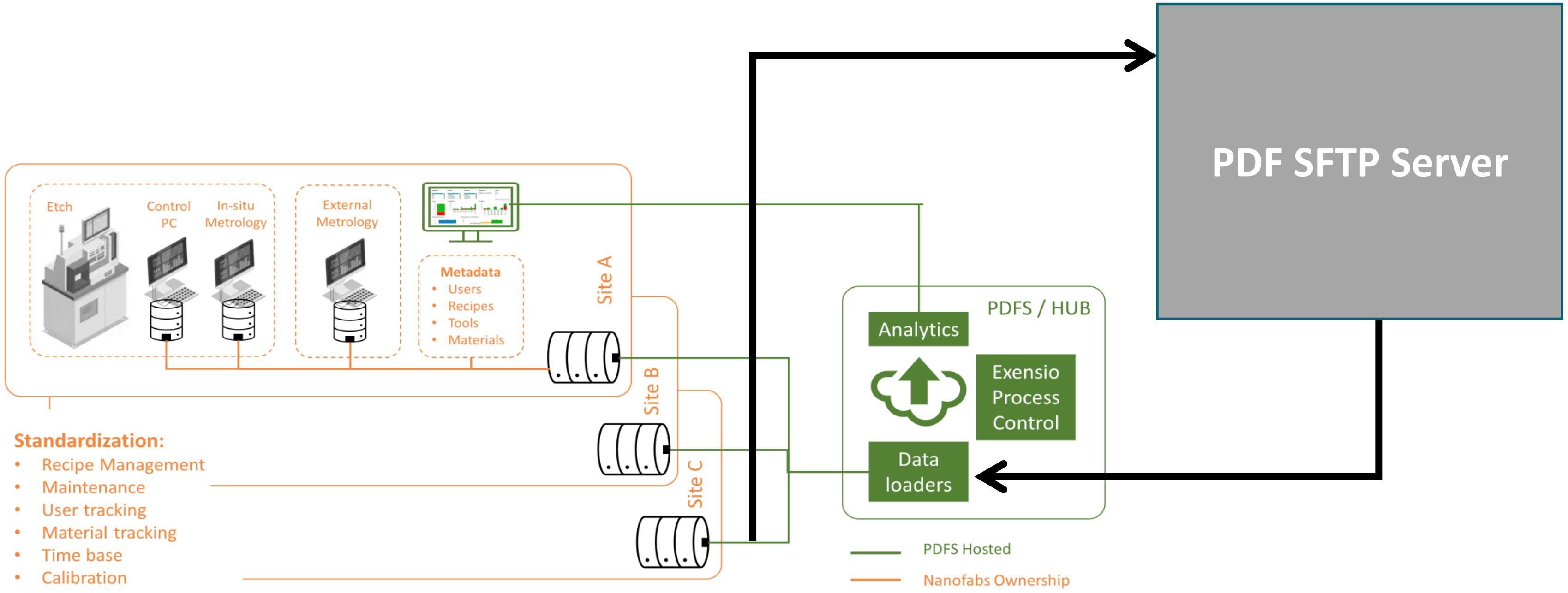
- **SPC control to detect system failures before process failures. – Be proactive.**
  - Automated to minimize staff resources needed.
  - Provide assurance of machine health – active alerts to staff
- **Correlation of outputs to machine sensor values (including OES).**
  - Reductions in process calibration variance
  - Understanding and mitigation of differing materials' effects on system state.
  - ID causes of machine drift and systematic output variance
- **Process outlier analysis to ID root causes when results are out of spec.**
  - Anticipate outliers before product failure – failure reduction, machine improvements.
- **Use Analytics software to improve process transfers – Machine matching**
  - Reduce lab to fab and fab to lab process module transfers.
  - Matched processes in lab and fab means less risk(and time) for transfer.
- **Everything to reduce failures, improve lab development times, increase ability to process transfer.**

Improving Outcomes and Reproducibility with PDF Solutions
With Fatt Foong, Noah Dutra, Vraj Mehalana, PDF support (Jackie, Weldom, Aruga, Samuel, Rock)

UCSB

PDFSolutions Exensio Cloud Based implementation at UCSB (also at USC, UCSD)

- Get output data (etch rate, etc.) for calibration (or user) recipes linked to meta-data uploaded to PDF.
- Upload files to PDF server at a regular interval – every few hours at present.
- Work with PDF engineers to evaluate data from the systems over time for repeated calibration recipes.
- Obtain software training to use on our own.
- Integrated external OES to datasets for etchers.
- Use correlative analysis and outlier analysis of data to improve or ID issues.
- Set up SPC on machine health recipes (chamber cleans) for reliable data on system state.
- Exensio Analysis is enabling many improvements.



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Process Control - Improving Variance

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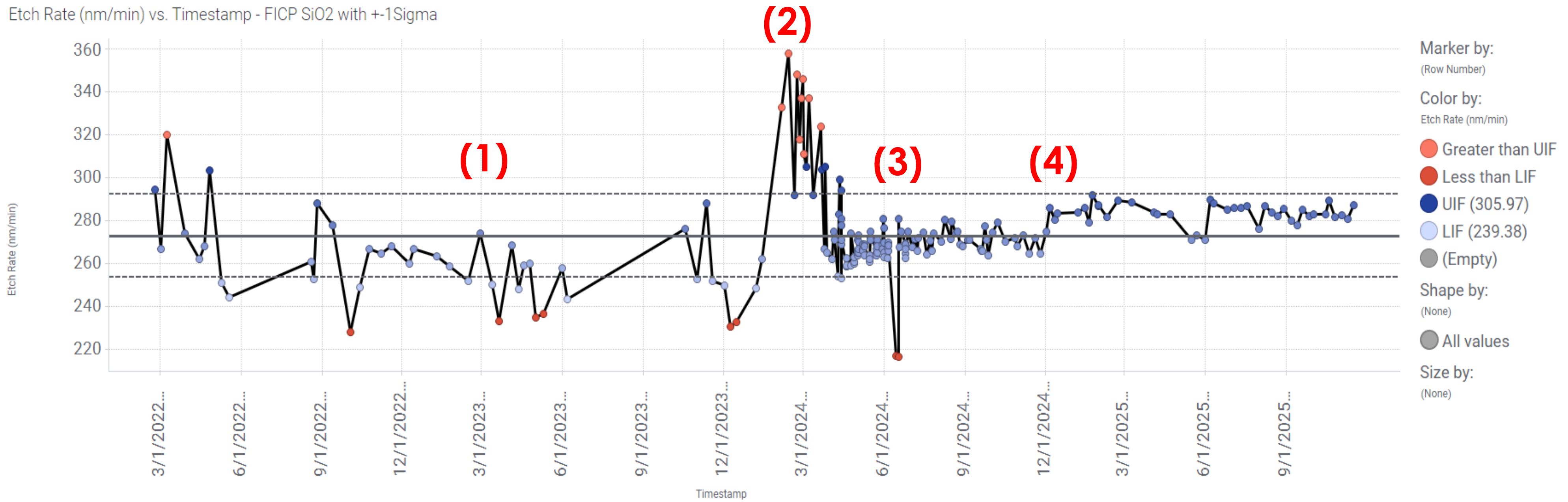
SiO2 etching – heavily used recipe – PlasmaTherm SLR.

- Imported and assessed historical data variance **(1)**
  - No sensor correlation up to to early 2024. Increased data rate (interns)
- Clamp broke – Feb. 2024 **(2)** – Strong DC bias correlation with rate, wrong clamp design – inventory issue
- Improve experimental and measurement techniques.
  - Reproducibility dropped to better than +/- 5% **(3)**
- Small shift late 2024 – RF tuning circuit recalibration **(4)**
- **We now have long term control and reproducibility.**



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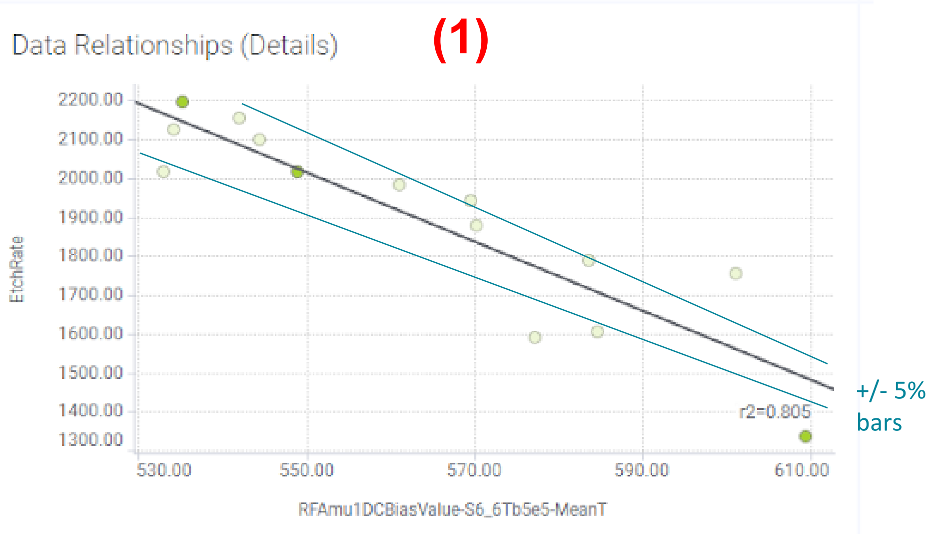
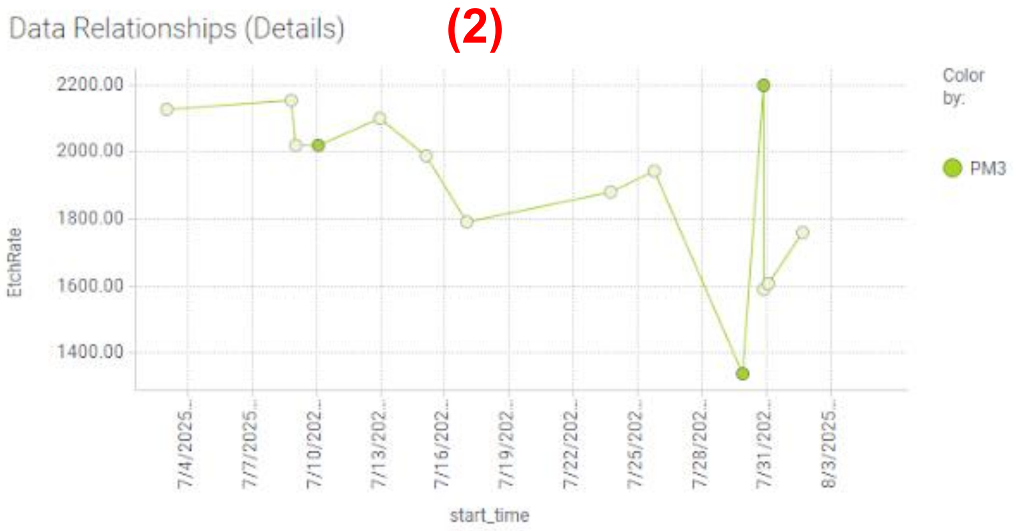
Process Control – Feedback

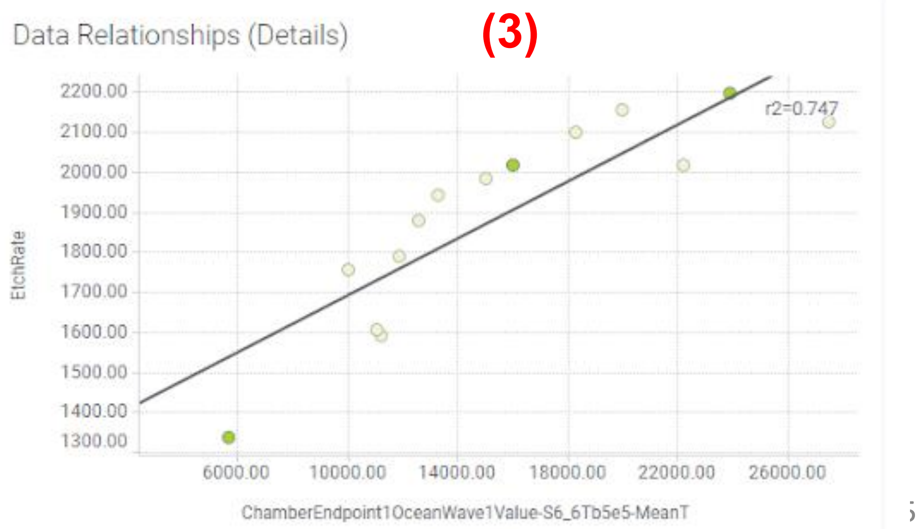
UCSB

InP etching –Sensitive Process. – Oxford Plamsa Pro100 200C etch

- Historically +/- 10% with additional outliers.
- Observed rate drop with DC Bias **(1)** and with Time **(2)** (chamber condition?)
- Second correlation family with plasma OES signals. **(3)**
- Hypothesized plasma density changes – measured ICP power vs DC Bias – directly correlated.
- **Now Investigating feedback control on ICP bias for improved ER control.**







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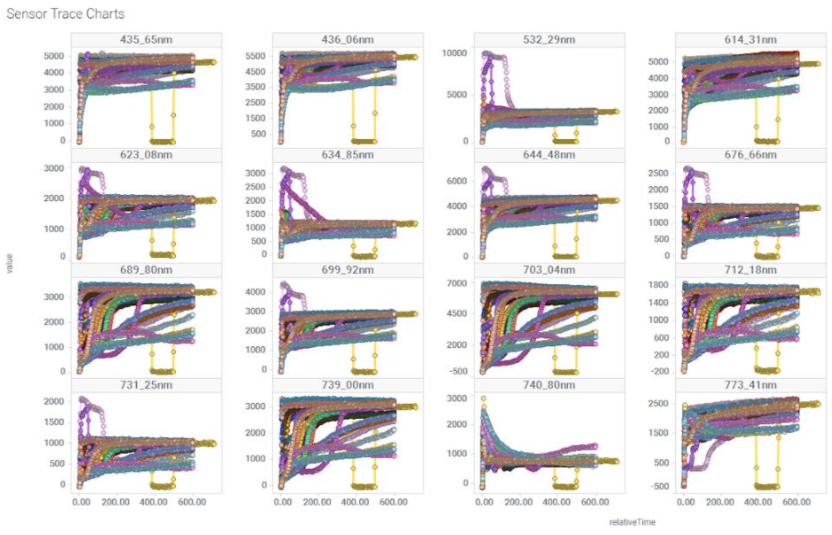
Process Control – Chamber Conditions

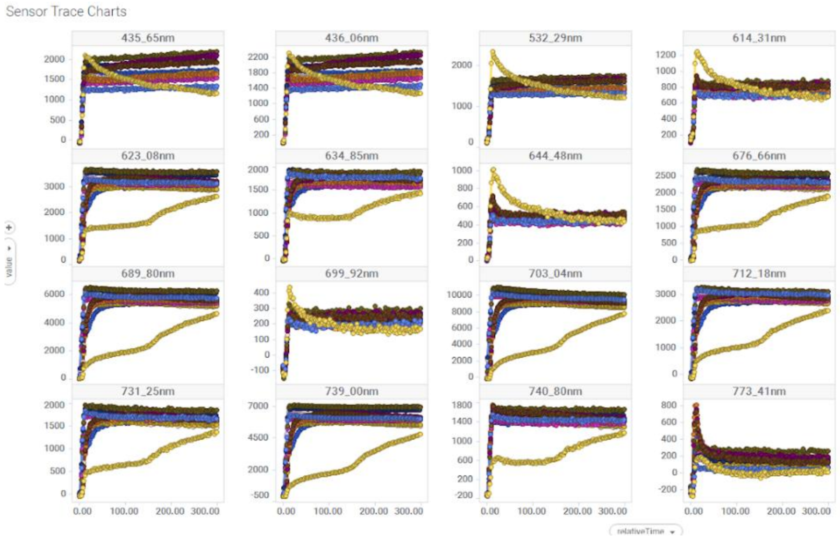
UCSB

Chamber Cleaning – Final State Consistency

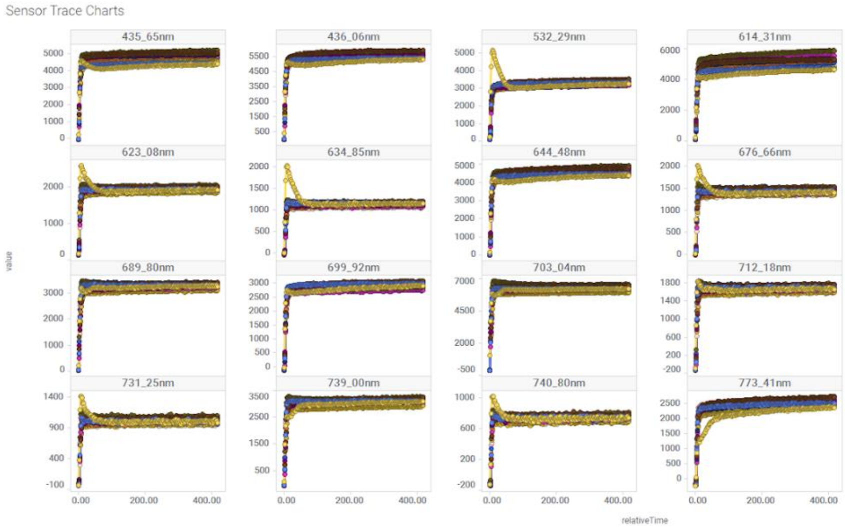
- OES signals from multiple clean runs prior to calibration etches. 16 wavelengths shown.
- Original recipe 10 min SF6/O2 Clean
  - Very inconsistent end state
- Switching to SF6 + SF6/O2 in sequence recipe.
  - Consistency dramatically improved.

Original SF6 + O2 Only clean





SF6



SF6 + O2

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Process Control and Outliers

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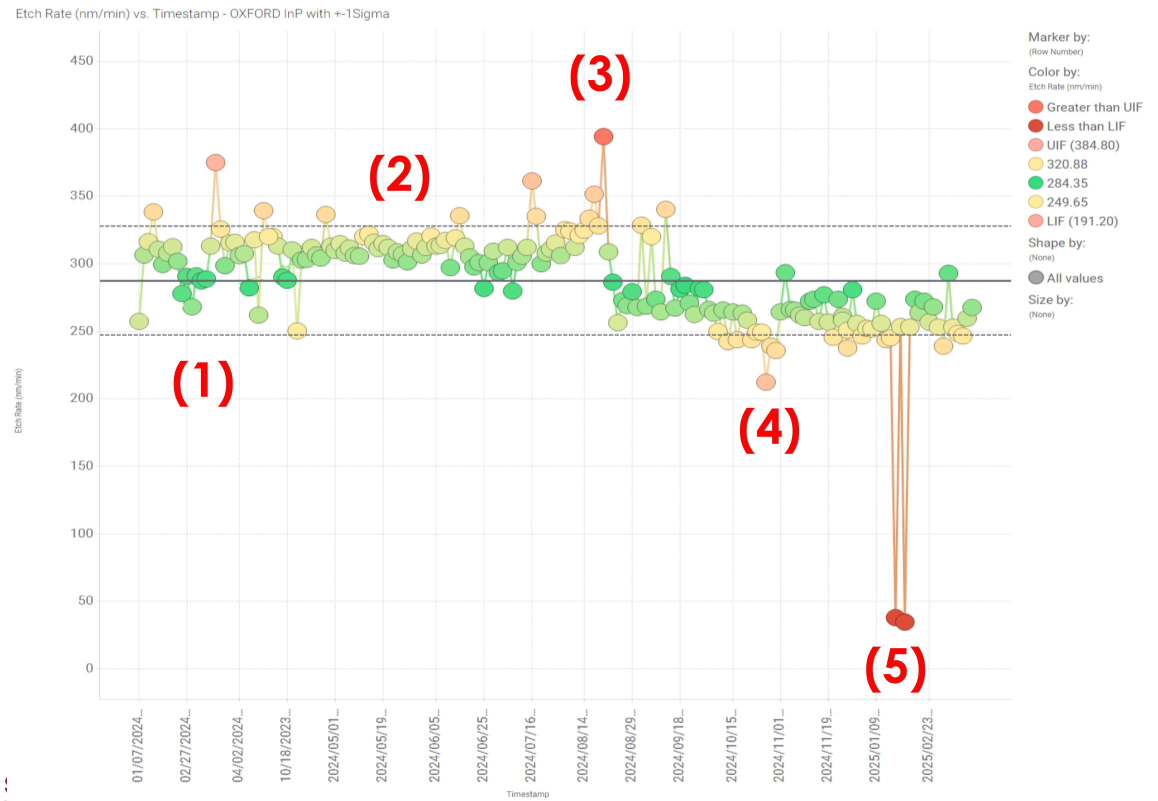
InP etching – All compound semi etch, ITO etch. Cl2 based.

- Similar to SiO2 etching: early 2024 no major correlations **(1)** – increase data (Interns)
  - Reproducibility improved with tightening experiment/measurement procedures. **(2)**
- Use WQR analysis to ID reasons for outliers and take action. One stop check for sensor differences between outlier and any number of previously successful runs.



Outlier Examples

- **(3)** High etch rate. Intern forgot to run a season recipe – found in Exensio sequence of events.
- **(4)** Low etch rate. Plasma turned off and then on again from WQR in Exensio (automatic comparison of this run with good runs).
  - Cleaned system.
- **(5)** RF issue – plasma not lit – not caught by system
  - Discovered Ignition issue upon log trace reviews. Stabilized ignition with recipe change
  - Found recipe issues with DCV alarm setpoint. Notified Users

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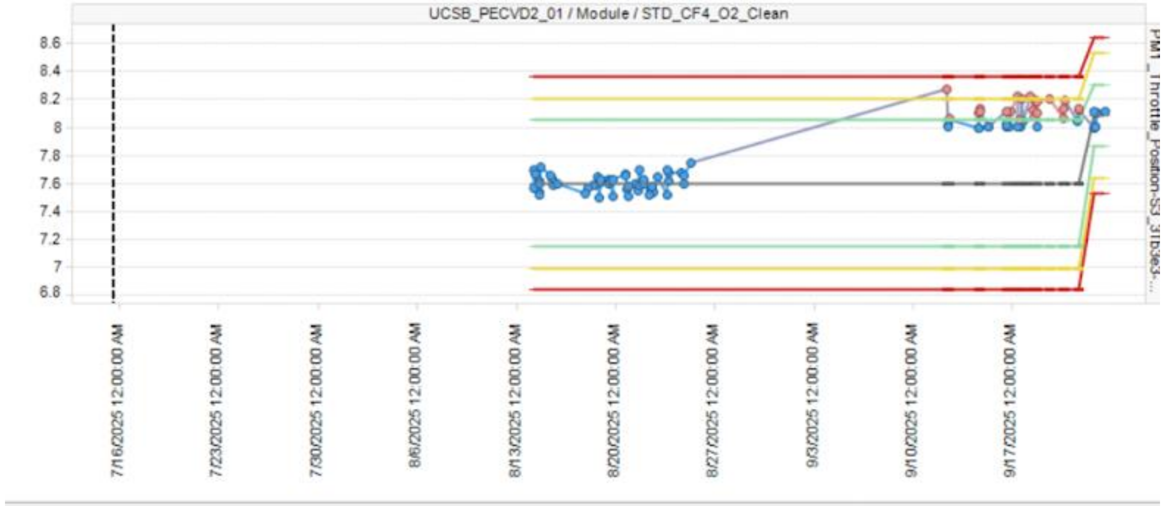
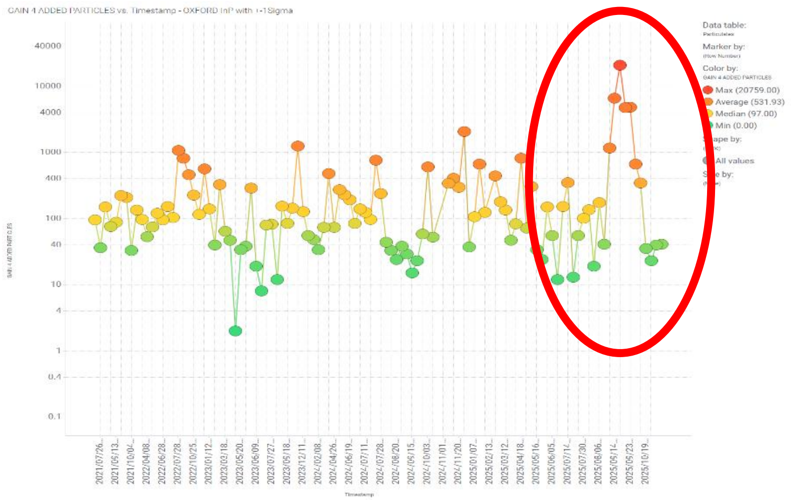
Dashboards for Efficient SPC Feedback

UCSB

PECVD and Etchers – Quick Visualization – Auto Emailing

- One stop quick daily check of all machines – one dashboard for all machine recipe variances.
- Look at Clean recipes – All users required to run – Lots of data
- Look back 10 to 1000 runs or more. Set SPC levels manually or based on data ranges – Email when outside SPC ranges
- Quick digging into problem for SPC chart and traces
- Example: PECVD – Saw throttle valve position shift at pumpdown (seal leak).
  - SPC values set too large – did not see quickly enough. System would still run. Huge particulate issues seen at time. Found/fixed leak. Tightened SPC.





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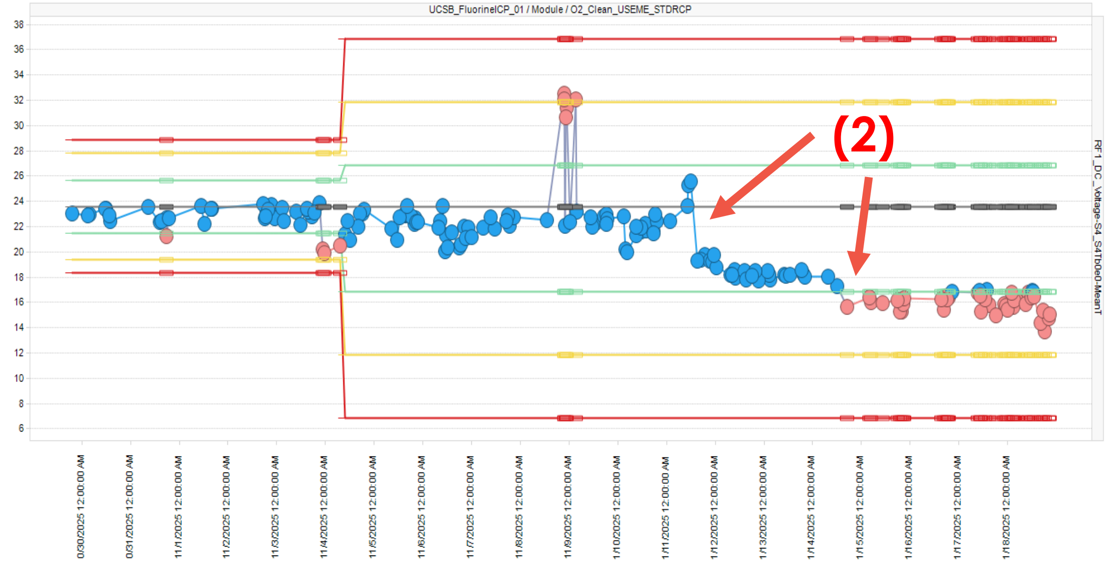
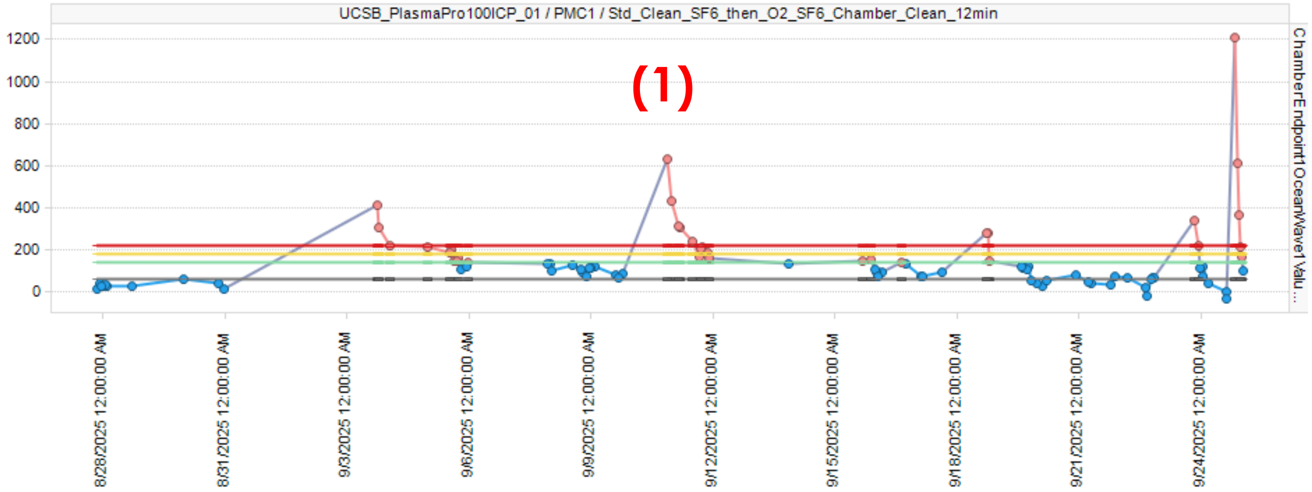
Dashboards for Efficient SPC Feedback

UCSB

Etcher Examples

- Oxford Etcher – After each opening, we noticed Hydrogen OES peak levels stayed high for some time. (1)
  - Use longer O2 clean after opening – water still around. – Caught by SPC dashboard.
- Flourine ICP – SPC caught DCV drop. Investigated.
  - Step-wise drops due to very long sequential SiO2 etches with no cleans in between. (CHF3 issue). (2) One particular user.
  - Leading to Si etch rate drop (outliers).
  - Maximum etch time established before O2 clean requirement.





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Helping Customer Quickly ID Etch Issue – InP example

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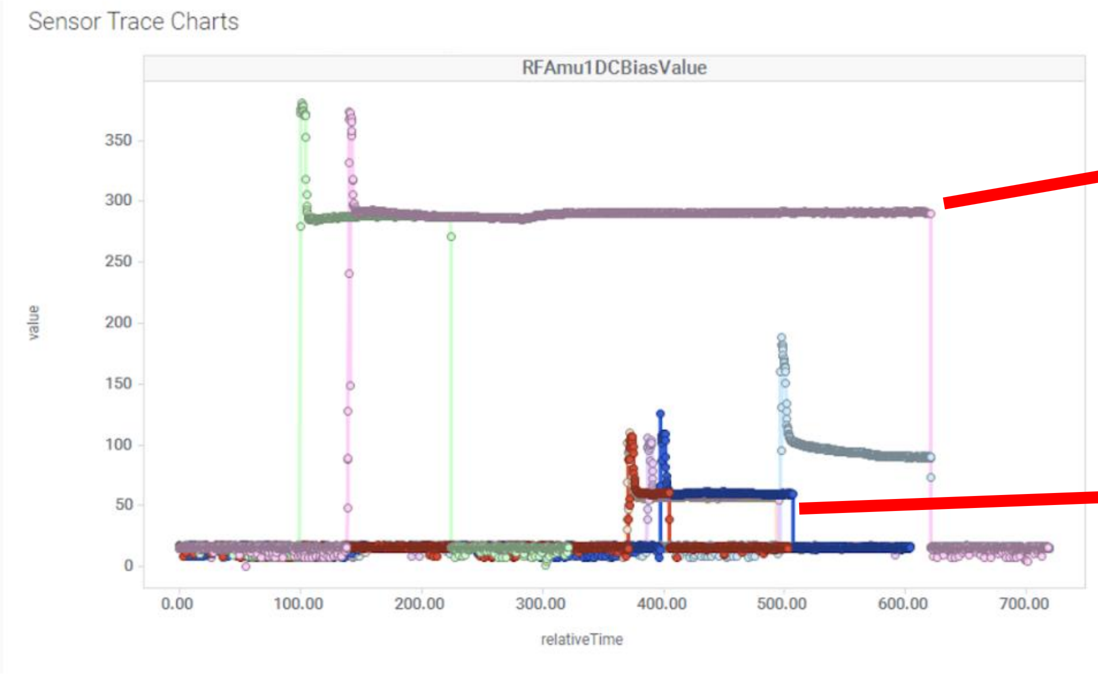
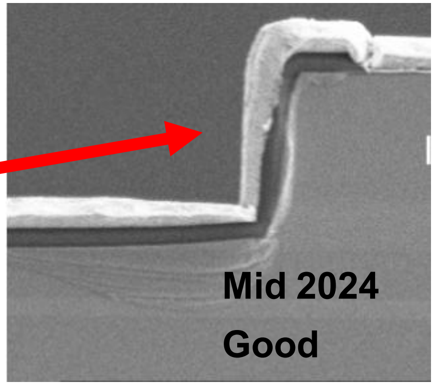
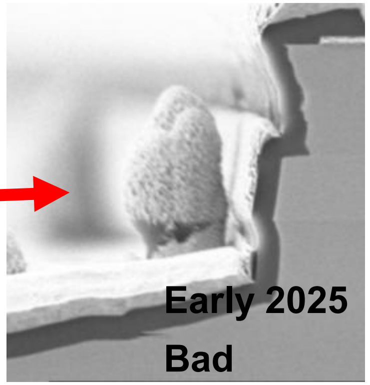
User Identified an InP based etch issue.

- Recipe is a Cl2/H2/Ar at 200C Table temperature recipe.
- InP calibration data showed consistent machine operation during "failed" etches.
- Had Exensio perform WQR analysis on recipe differences and sensor differences.
- Saw significant difference in DC bias form old runs versus new runs.
- Possibly used wrong carrier wafer – AlN instead of Si. Verified technician mistake with carrier wafer.
- **Automated Correlation of Machine data IDs the problem quickly and efficiently.**







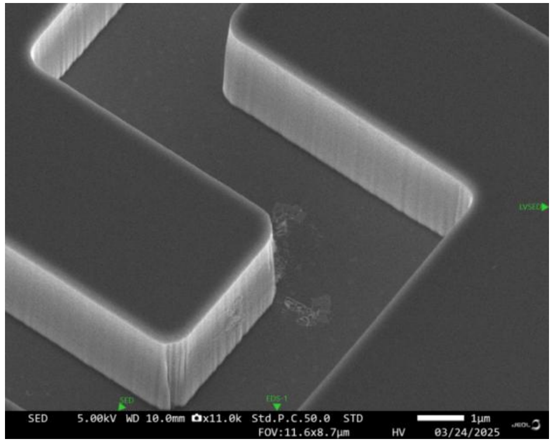
Towards efficient process transfer – First results

Additionally with Shivakumar Bhaskaran and Chandan Ramakrishnaiah at USC

UCSB

Goal: Transfer processes from lab to lab (or fab) efficiently. Demo/test with USC

- First experiments: Use similar systems but with different chamber geometry.
- Performed multi-level DOE for InP etch around a baseline process to map both system sensitivities. Machine parameters easily compared through Exensio with access to both output and sensor data sets in the software.
- Trends were mapped to give scaling factors from one system to another within Exensio.
- Established new recipe in GaAs at UCSB.
- Using the match conditions form the InP DOE– Create etch parameters for USC. Sent them same material. All measurements at UCSB.
- **Result: Transfer on a single experiment very close to identical. Working on improving methodology and repeating with other systems. Working on UCSD transfer, additional USC transfers, 4" to 6" machine conversion transfer.**



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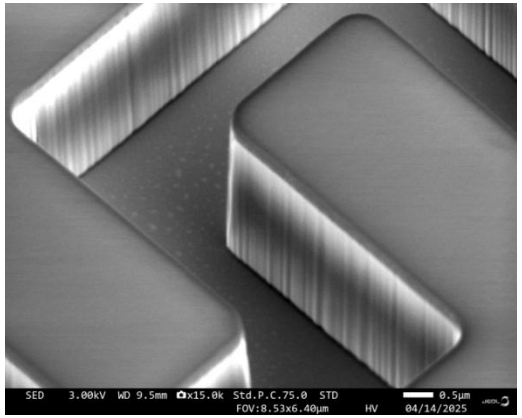
Etch rate 1000nm/min

Mask select: ~38



USC

Etch Rate 1030nm/min

Mask Select: ~41

Lab to Fab: Process Transfers/Process Matching with Teledyne

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TELEDYNE SCIENTIFIC & IMAGING
Everywhereyoulook™

Working with PDFS

- Assist Teledyne with Exensio use in their mixed materials facility.
  - Transfer both knowledge and scripts.
- Match processes.
  - Gives Lab customers processes already in foundry for more efficient transfer
  - Lab can serve as backup for Fab processes – Exensio matched and monitored systems.
- Transfer new Lab processes into Fab flows
  - Can perform split lots with Lab process inserts.
  - Transfer Lab processes to Teledyne fab for incorporation .

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Thank You

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