

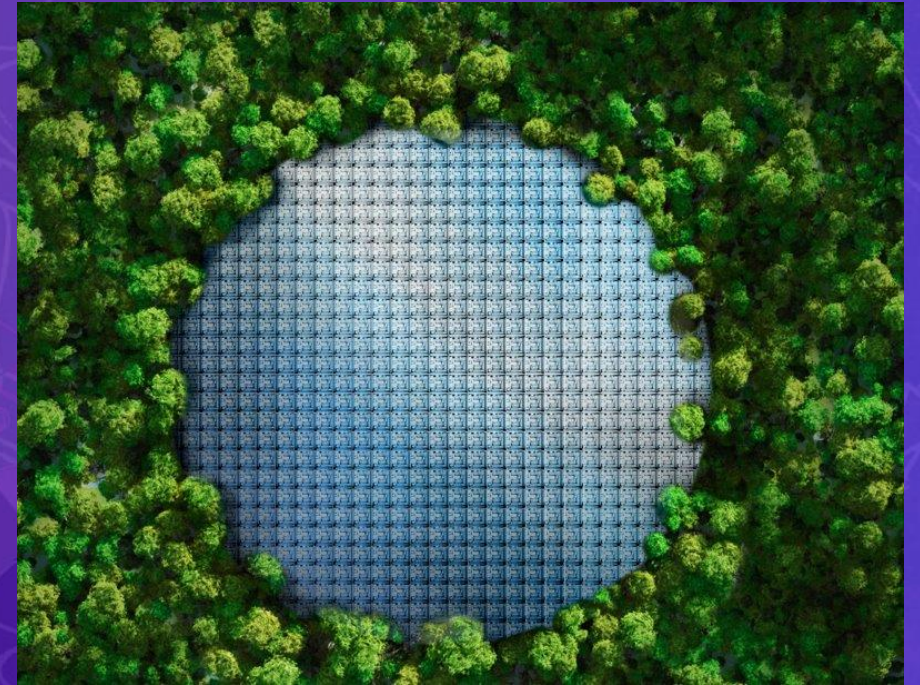


Use of chemical process control as a path to increased sustainability – New insights

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November 14, 2023

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs...



Overview

- **Accessing semiconductor industry sustainability**
- **Global sustainability goals and status**
- **Holistic material health monitoring**
- **Component byproduct detection**
- **Summary**

Semiconductor Industry and Sustainability

Resource intense

- Fabricating a single 2G chip requires 32kg of water, 1.6kg of petroleum and 72g of chemicals – and billions of chips are produced every year
- TSMC, the world's largest chipmaker, emitted around 15 million tons of CO2 in 2020 – surpassing automaker General Motors' emissions

Highly innovative

- The introduction of extreme ultraviolet (EUV) lithography reduced the number of process steps needed as scaling continued. Associated per wafer energy consumption for EUV processing alone is projected to double from 7 nm to 2 nm node.

Very cost conscious

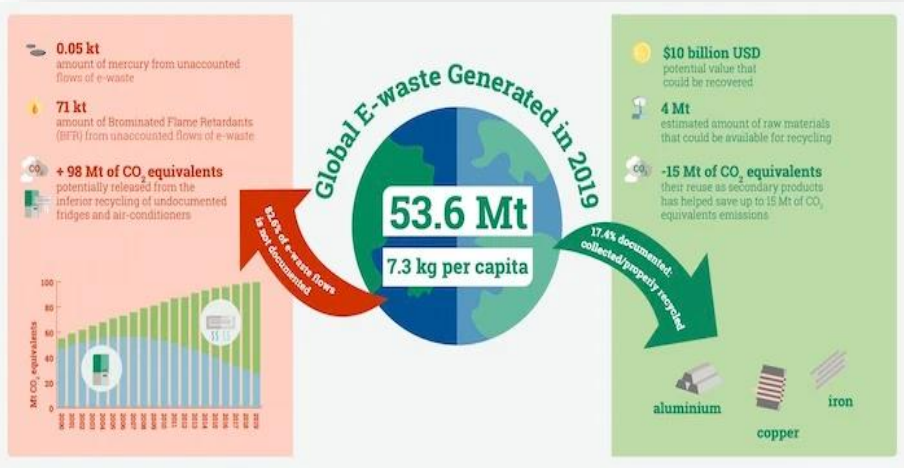
Moving towards sustainability

- SEMI - Semiconductor Climate Consortium (SCC) with 60 founding members from across the semiconductor value chain, Sustainable Semiconductor Technologies and Systems (SSTS) research program by IMEC
- ASE, Intel, STMicro, TI, Ebara, TSMC, UMC, SK Hynix, Infineon, On-Semiconductor – making it to worldwide, top sustainable companies list across multiple sectors
- Many many more...

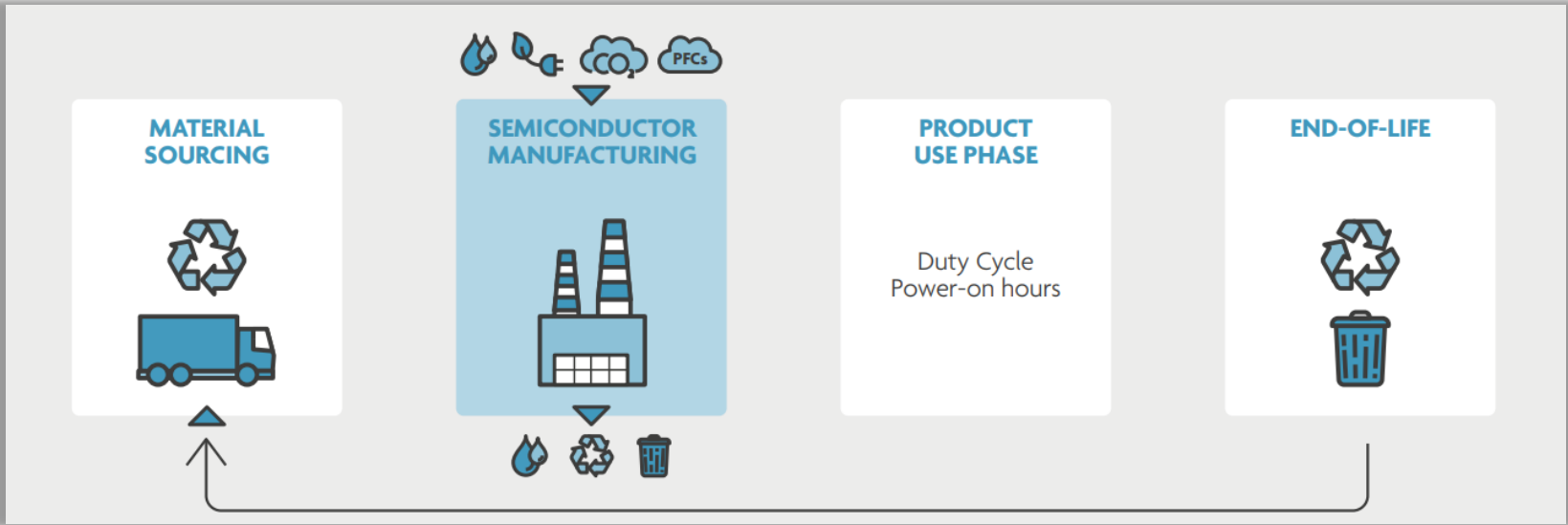
Semiconductor Product Lifecycle – Life Cycle Analysis

Impact category	Manufacturing	USE	Transport
Carcinogens	85%	10%	5%
Non-carcinogens	95%	5%	1%
Respiratory inorganics	40%	40%	20%
Ionizing radiation	5%	95%	1%
Ozone layer depletion	70%	10%	20%
Respiratory organics	45%	15%	40%
Aquatic ecotoxicity	40%	55%	5%
Terrestrial ecotoxicity	50%	40%	10%
Terrestrial acid/nutri	35%	35%	30%
Land occupation	30%	30%	40%
Global warming	40%	35%	25%
Non-renewable energy	10%	80%	10%
Mineral extraction	99%	1%	0%

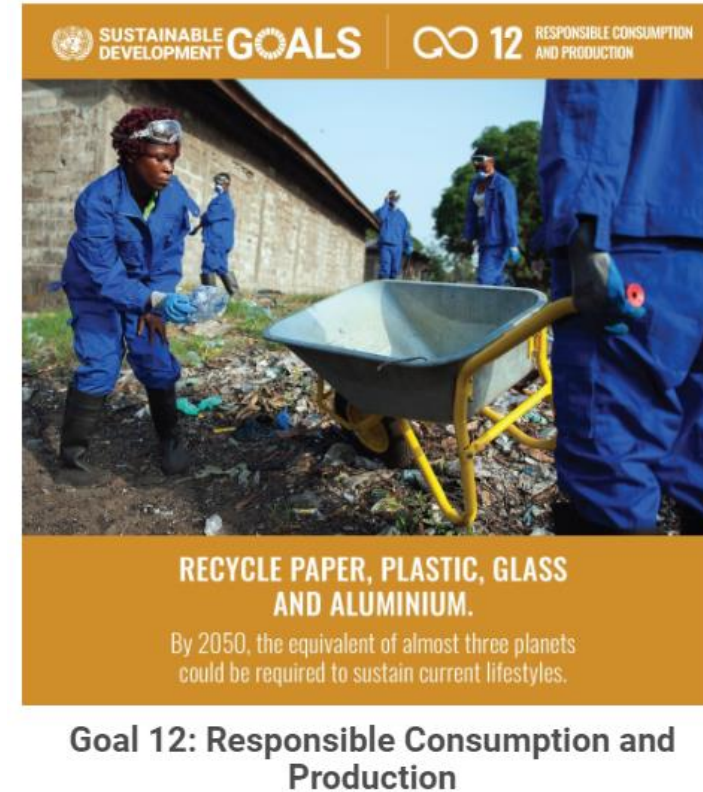
Relative fraction of impact on a specific resource category by Manufacturing, Use and Transport parts of semiconductor product lifecycle



E-Waste is a global problem, with over 7 kg of it generated per capita in 2019, and growing, and still insignificant portion being properly recycled



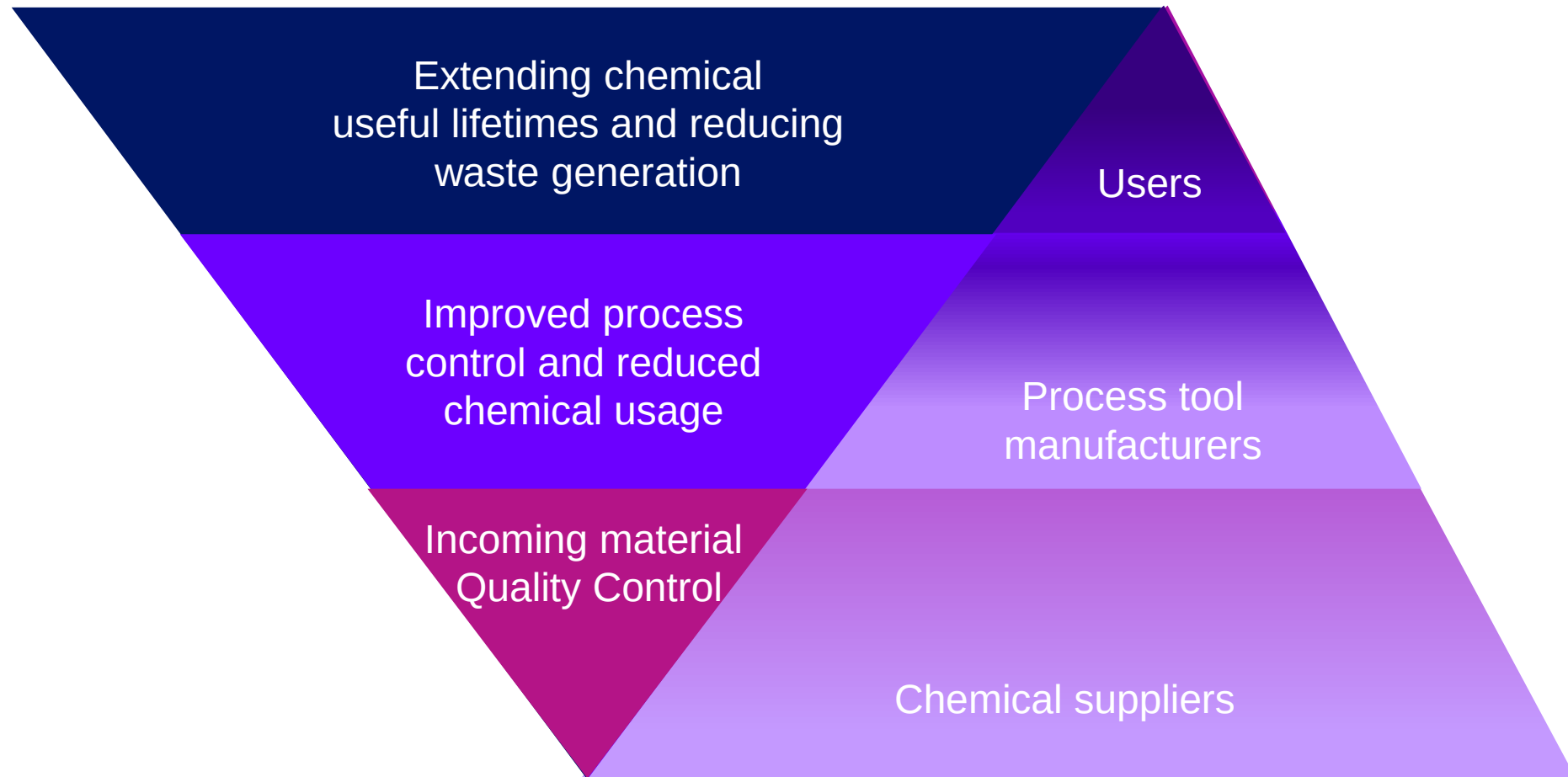
UN's Sustainable Development Goals 2030 (SDGs)



12 RESPONSIBLE CONSUMPTION AND PRODUCTION	
12.1 Programmes on sustainable consumption and production	●
12.2 Sustainable use of natural resources	●
12.3 Food waste & losses	●
12.4 Managing chemicals & wastes	●
12.5 Reduction in waste generation	●
12.6 Corporate sustainable practices	●
12.7 Public procurement practices	●
12.8 Sustainable development awareness	●
12.a Support for R&D capacity for sustainable development	●
12.b Sustainable tourism monitoring	●
12.c Fossil fuel subsidies	●

The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States in 2015. At its heart are the 17 Sustainable Development Goals (SDGs). Goal 12 is about 37% on track, ahead of the global average of 15% across

Our role – reducing chemistry use



Broadening collaboration between chemical suppliers, process equipment and end users at different stages of the material lifecycle



NOVA CMD

Chemical process control experts

Key Facts of NOVA CMD



2001 | Date Founded



Presence | Germany HQ. Global Offices



5 | Regional Sites



800 | Active Systems Installed-Base

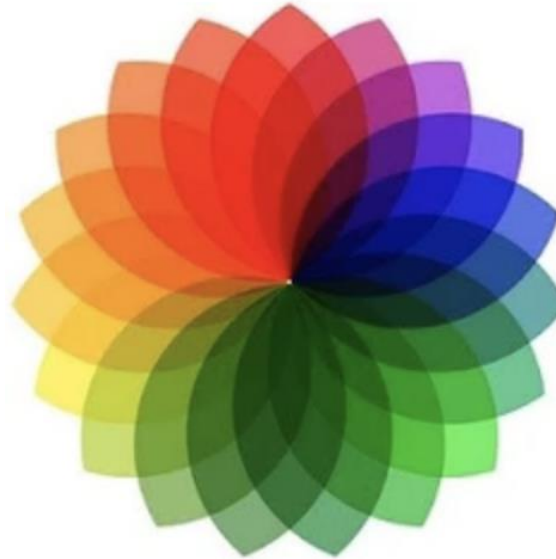


R&D | Germany

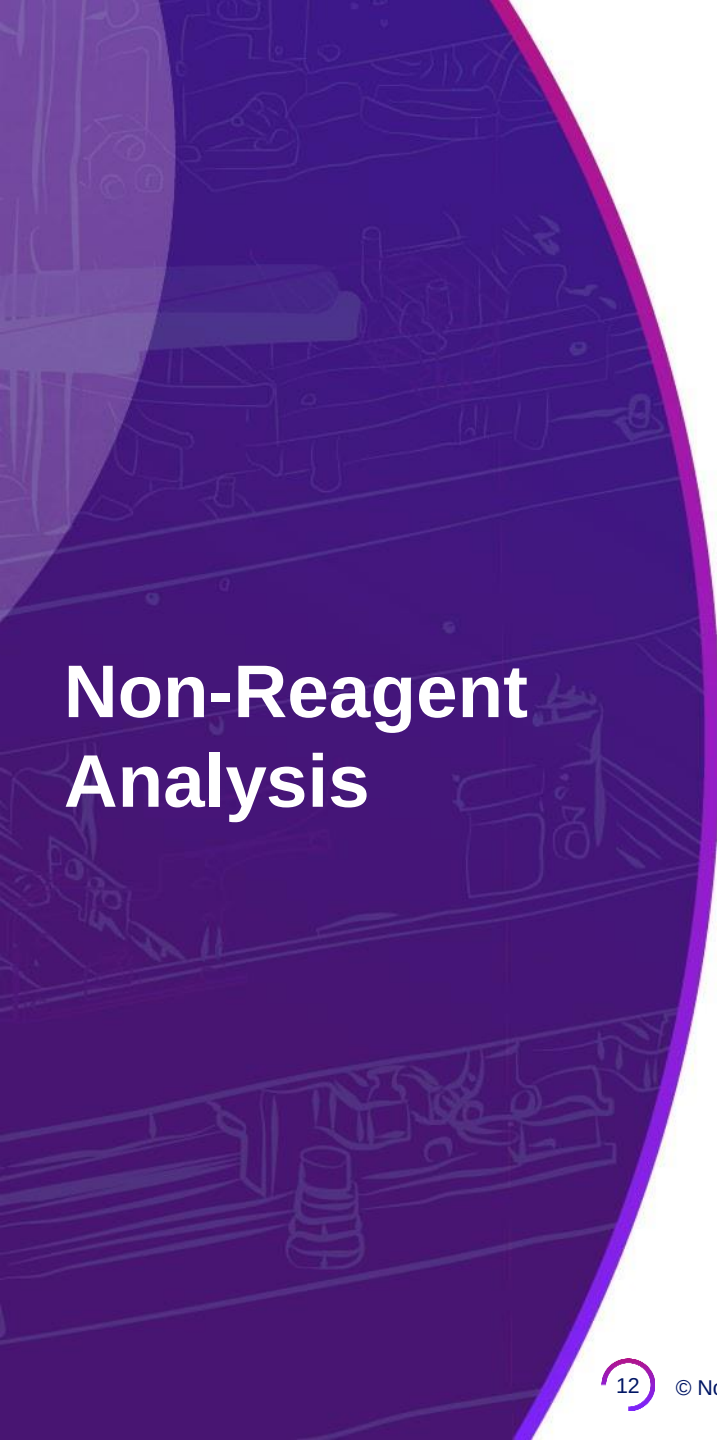


Variety of techniques for material characterization

- Titration (pH, redox, optical, precipitation, others)
- HPLC (High Performance Liquid Chromatography)
- Various Electrochemical techniques:
 - CVS
 - CPVS
 - DPASV
 - PCGA
- GPC (Gel Permeation Chromatography)
- mVECA Health Indicator (multi variable electrochemical analysis)
- Total Organic Carbon (TOC)
- Density, Specific gravity
- Redox potential
- Surface tension
- Conductivity
- Refractive index
- Temperature
- LPC (Liquid Particle Counter)
- Zeta potential
- NIR
- Raman
- ICP-OES



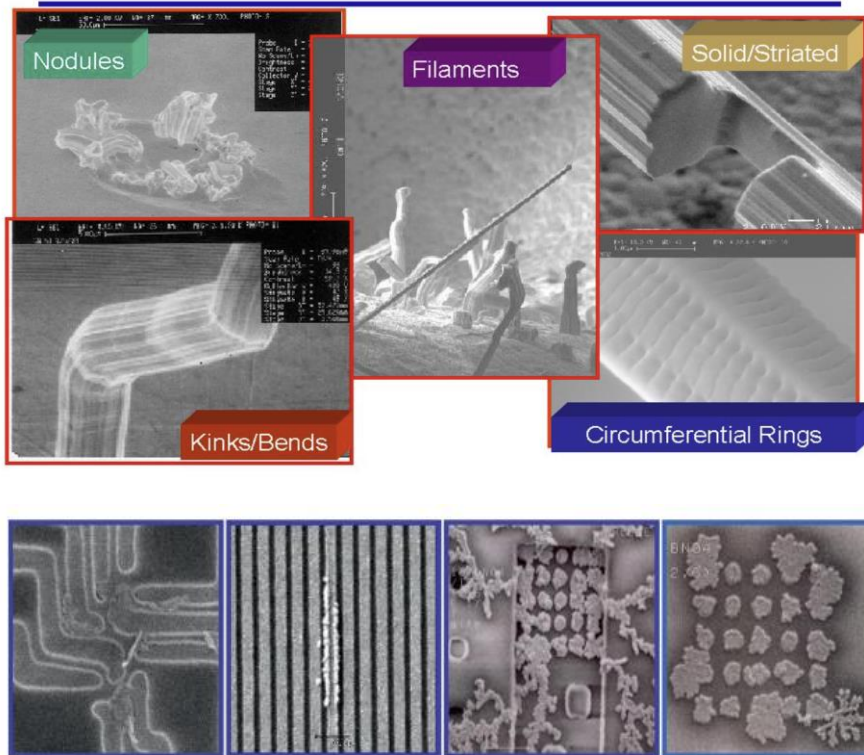
Individual components, macro-characteristics and holistic performance indicators to characterize both physical and chemical properties - analyze **Inorganic** and **Organic** components, **Breakdowns** and **Behavior**



Non-Reagent Analysis

Reducing chemistry use

Solder bump defectivity - Investigation

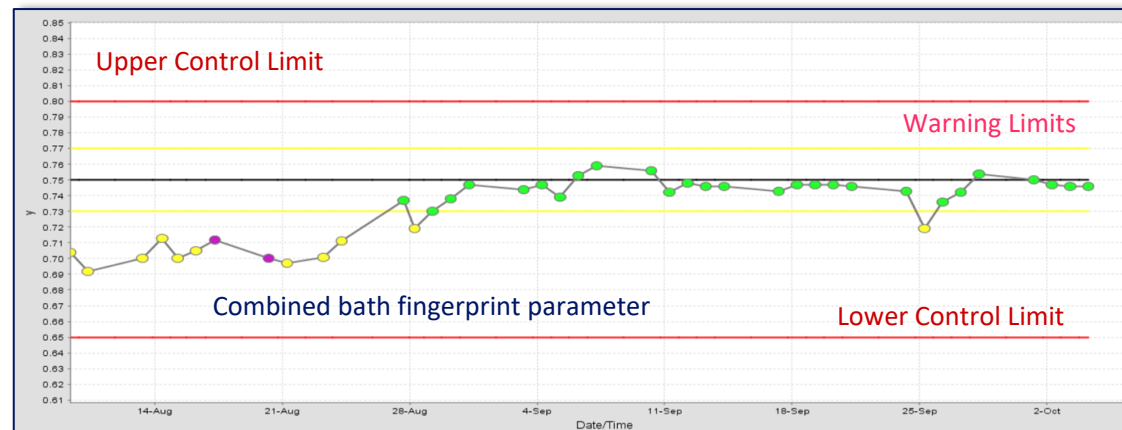
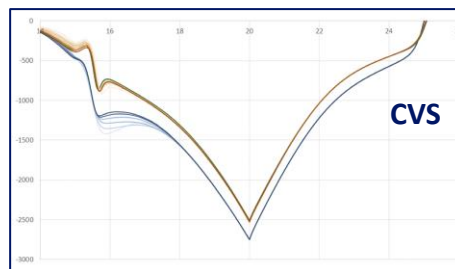
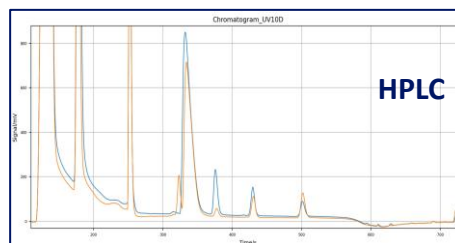
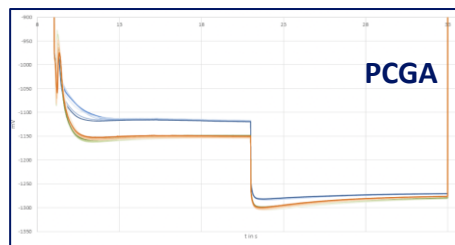
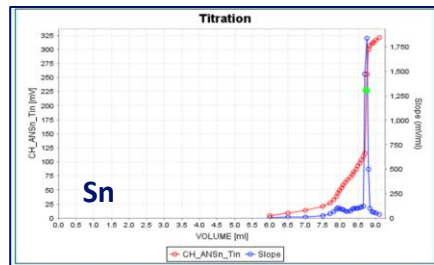
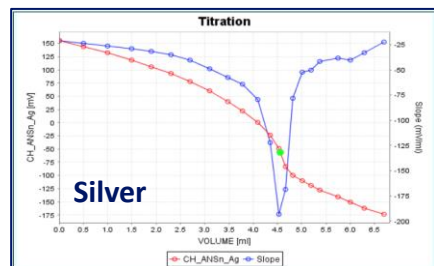


- At one of the leading-edge semiconductor manufactures one bath, out of the fleet of multiples shown plated structure defectivity
- For all tools running this Tin-Silver process all individual component indicators are measured in specification window
- Adding more chemical consuming methods or tightening process control window is not a popular, or an effective option
- Developing methods of process control directly tied to process and functionality is a must



Individual component analysis often does not show the full extent of material degradation

Simplifying process control EC screening - mVECA



- Tailored to the application
- **Fewer parameters to monitor**
- Simpler build with fewer parts
- To **supplement and strengthen** conventional analytics

Electrochemical Screening for Defectivity Control

- mVECA is an electrochemical monitoring method, designed to mimic plating process
- Specific plater (Plater 2) shown need shaped growth (nodules) – with other tanks showing no issues
- We monitor both processes related to different stages of plating deposit life cycle
 - Film nucleation
 - Crystal growth
 - Stripping
- mVECA tests identified differences between healthy and failing baths, even with all components being in specification limits

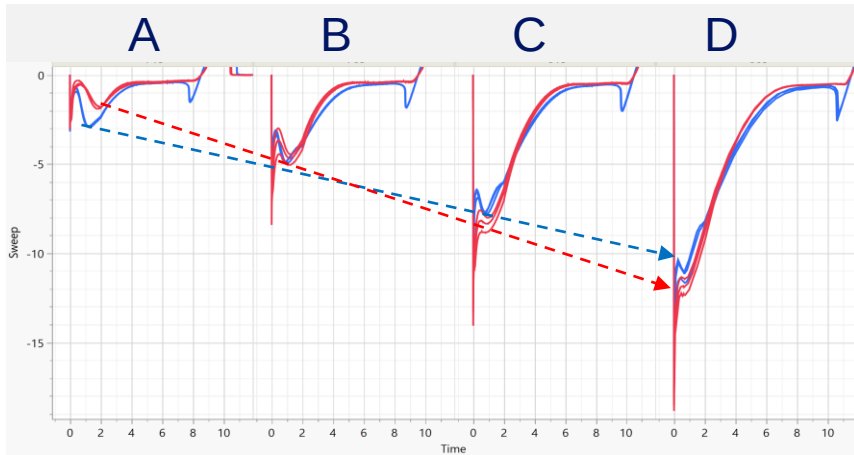
		NRP	RMSE_nucleation	RMSE_Crystal_Growth
	Standard	1.01	0.308158	0.3758522
	Plater 1	1.04	1.24067	1.746739
	Plater 2	1.11	2.673409	3.626703

mVECA results for Plater 2, both NRP and individual region readings show issues

		NRP	RMSE_nucleation	RMSE_Crystal_Growth
	CTRL	1.01	0.308158	0.3758522
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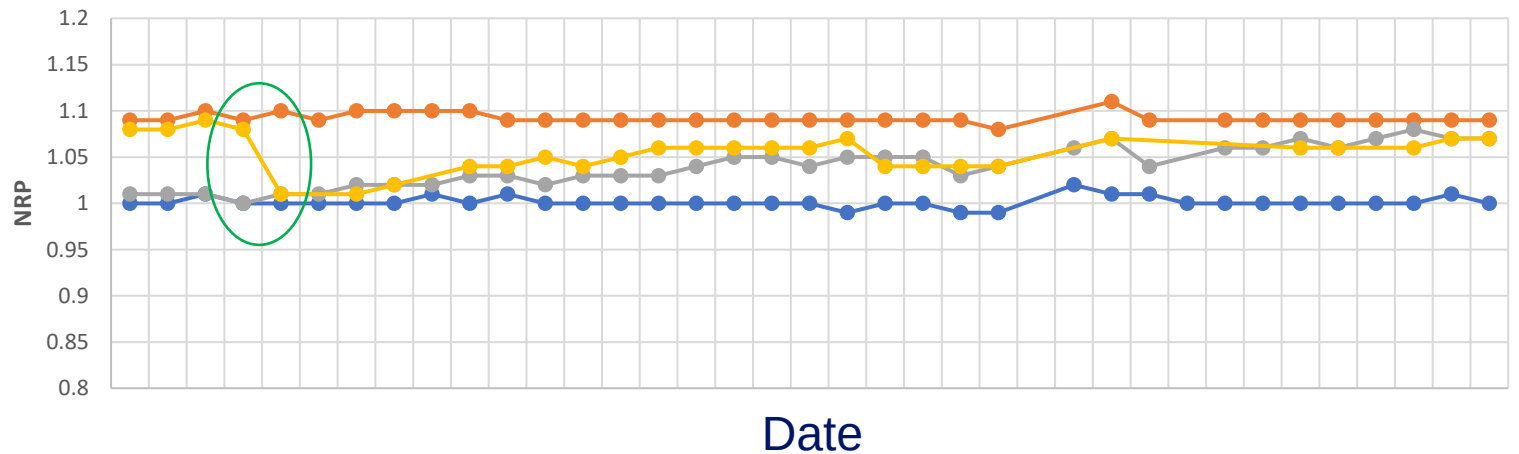
mVECA results for Plater 2, compared to STD and Plater 1

On-wafer defectivity investigation



Electrochemical sweep fragment highlighting differences between **healthy** and **affected** plating chemistry

Issues with plating bath in **Plater 1** only, other 2 showing no issues with the deposit quality



SnAg mVECA (multi-variable electrochemical analysis) is able to detect issues that correlated to deposit and reflow problems with the bath



Lab to Fab

By-product detection – extending lifetime

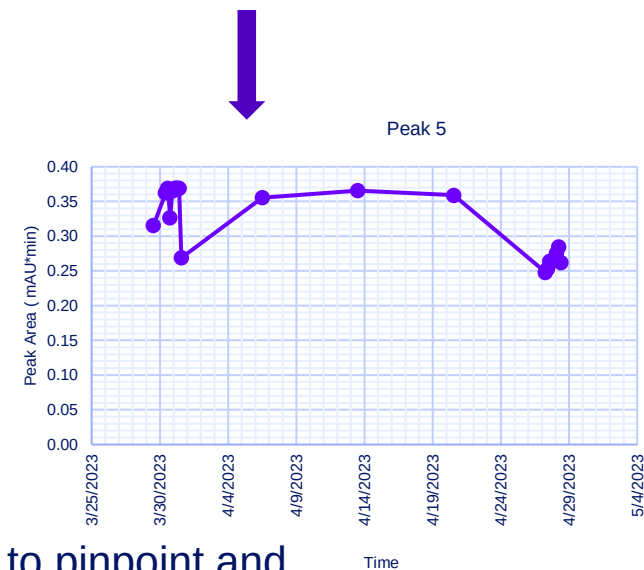
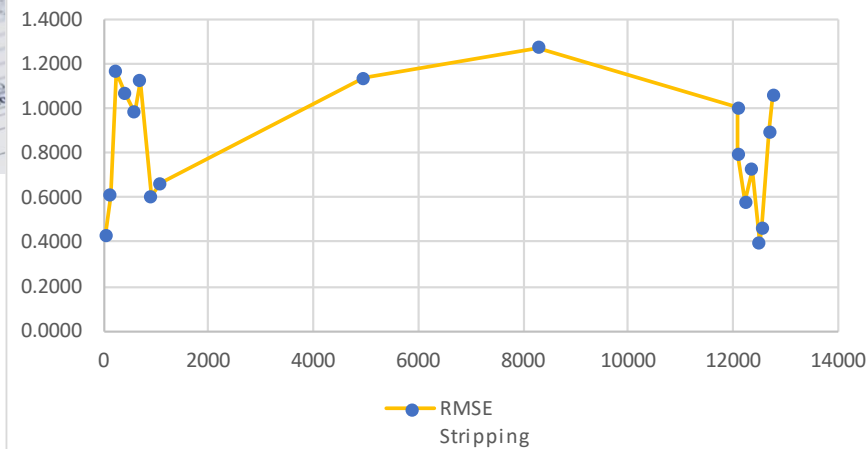
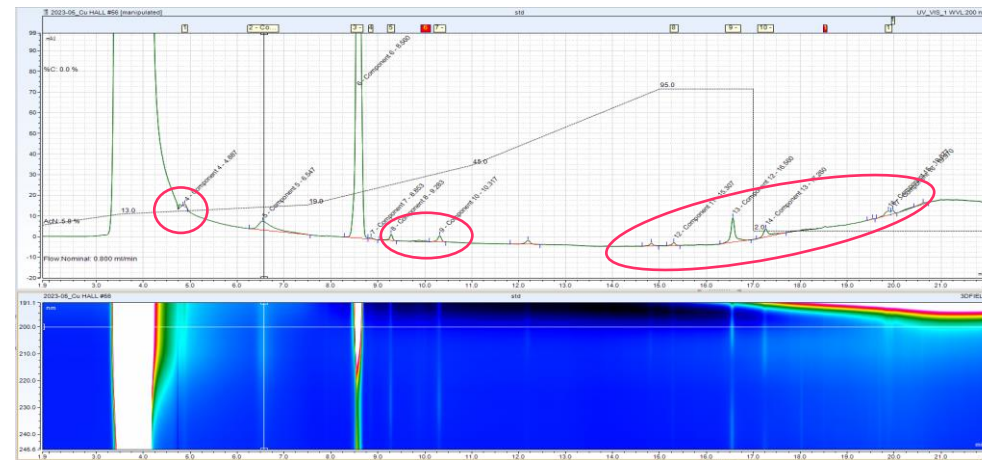
Problem Statement

- **During plating process** – especially at extended plating times (40 min or longer) **resist components** are **leaching into the bath, additive breakdowns are being built up**
- Additive breakdown and resist leaching and misprocessing – under-bake, coating issues (i.e., film pinholes and delamination) contribute eventual degradation of the plating solution
- To compensate – Bleed and Feed (10% - removal and replenishment with fresh components) is done
- Identifying metrics indicating issues and using them to reduce this Bleed and Feed rate is a **key to reducing chemistry consumption**

Summary – Combining Individual Data

Sample Week	Sample ID	Acc mL/L	Sup mL/L	Lvl mL/L	Temp °C
Week1	2023-03-29 12:30	12.74	2.39	1.03	40.0
	2023-03-30 10:00	12.21	2.47	1.17	40.0
	2023-03-30 14:00	12.15	2.42	1.00	40.0
	2023-03-30 18:00	12.31	2.44	1.01	40.0
	2023-03-30 22:10	12.36	2.42	1.01	40.0
	2023-03-31 02:15	12.51	2.51	1.01	40.0
	2023-03-31 06:10	12.32	2.47	1.00	40.0
	2023-03-31 10:00	12.44	2.53	1.01	40.0
	2023-03-31 14:00	12.42	2.50	1.00	40.0

9	0.3994	0.6148	1.2760
1	0.3981	0.3839	1.0067
5	0.3072	0.2631	0.7979
9	0.4001	0.4987	0.5819
6	0.4383	0.3908	0.7271

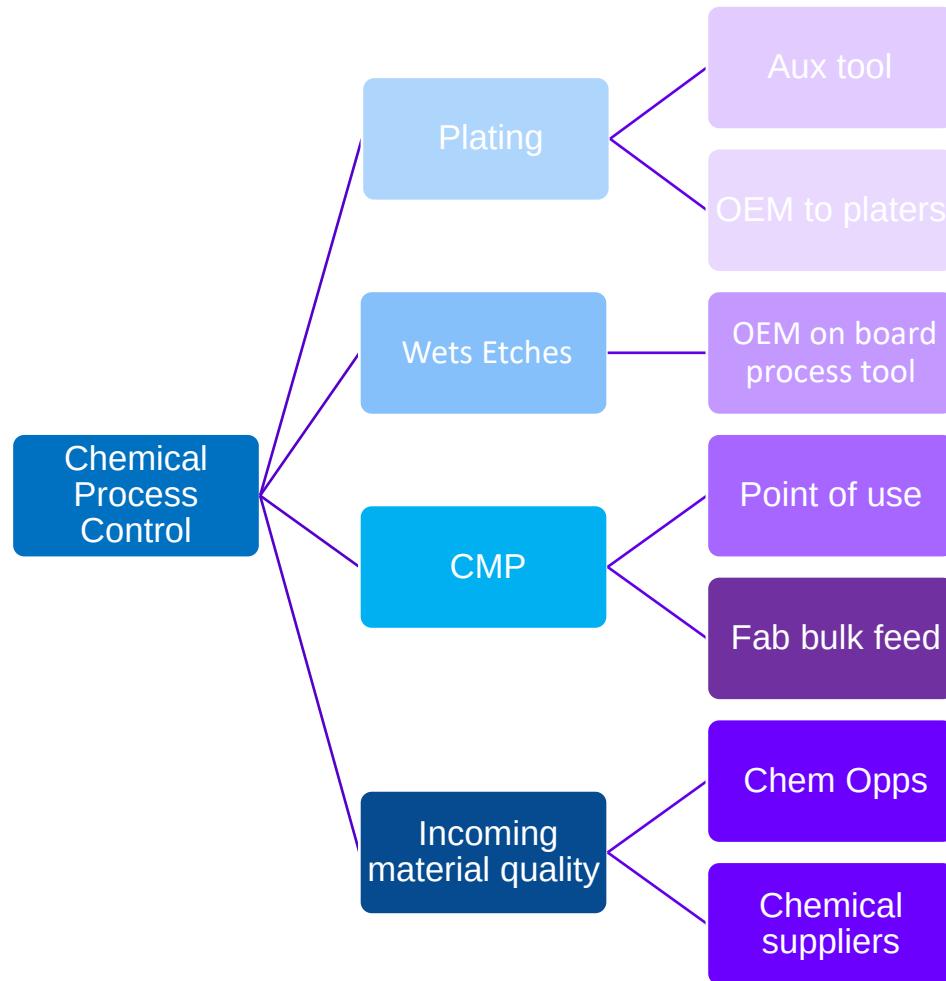


Correlating electrochemical results to the spectroscopic HPLC results allows to pinpoint and monitor components degrading bath performance, supplementing 7 individual variables

Summary

- Large variety of chemical analysis techniques is available at NOVA CMD to our users, including techniques fully tailored to the application
- Simply tightening the control limits does not help reducing chemical usage or improving process control
- Designing techniques relevant and connected to the processing step (EC in this case) can streamline and simplify overall control
- Improved process control = improved resource utilization with cost savings to the end use and reduce waste for the environment
- Part of the work shown here was supported via 14AMI European Consortium

Broadening Reach of Collaboration – Better Process Control



- Variety of elements of chemical process control can benefit a range of users – from chemical suppliers to individual processing tools
- Adding process control equipment with the right control techniques **will lead to reducing chemistry use and waste generation, preventing excursions and reducing stress on water supply**
- Reducing environmental impact of the process is our goal as we implement elements of chemical process control



We are at a critical junction, where broader range of collaboration directly translates to better process and resource savings

Sustainability is here to stay or we may not be...

Niall FitzGerald



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Thank You