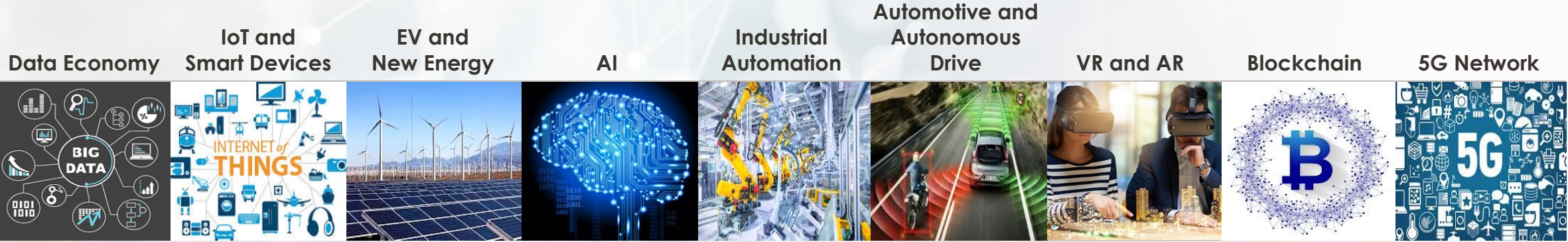


Materials Innovation: Holistic Solutions for Improved Yield and Reliability

James A. O'Neill, Ph.D.
Chief Technology Officer



9 megatrends that are shaping the industry.



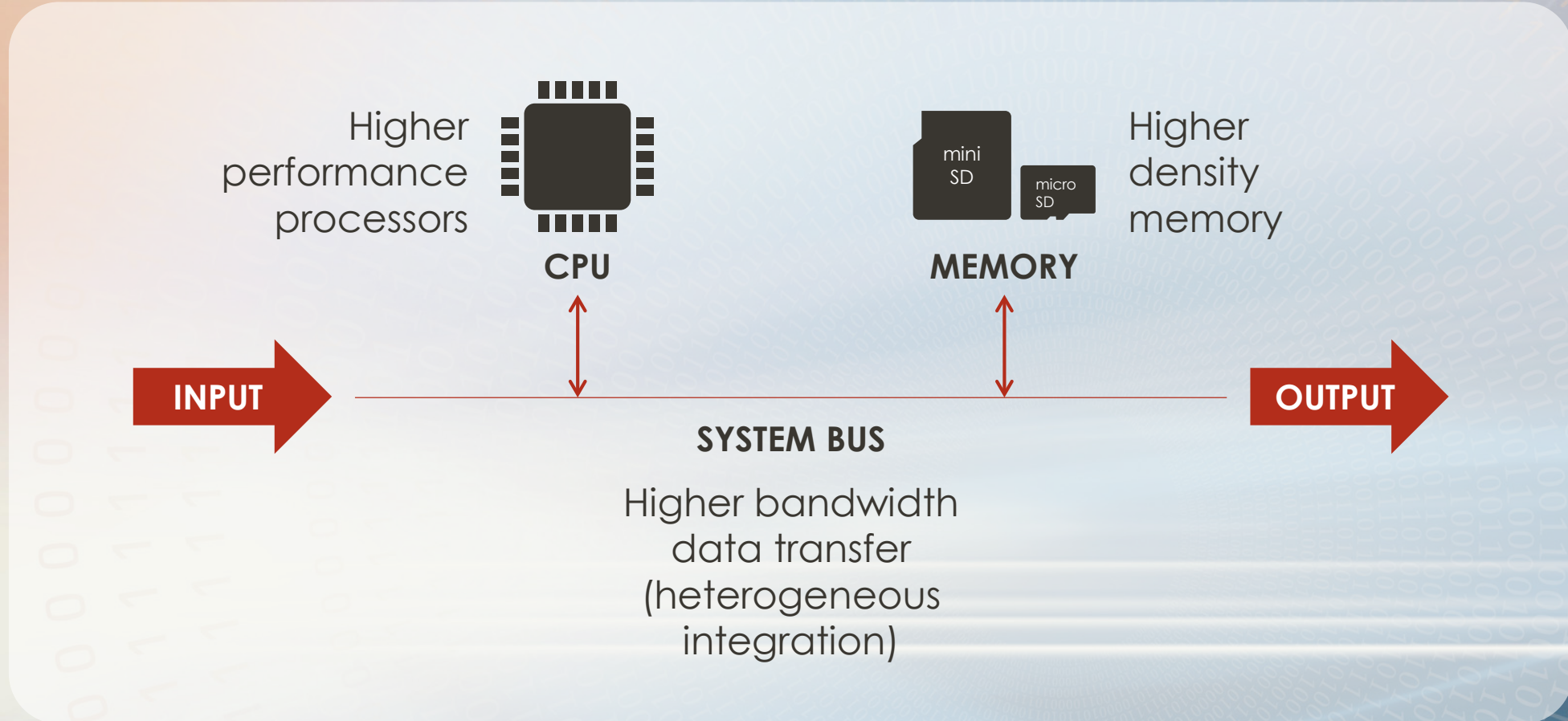
Virgiliu Obada | Dreamstime.com

Data explosion!

2.5 billion gigabytes of data per day

90% of data created in last 2 years

Von Neumann system architecture.

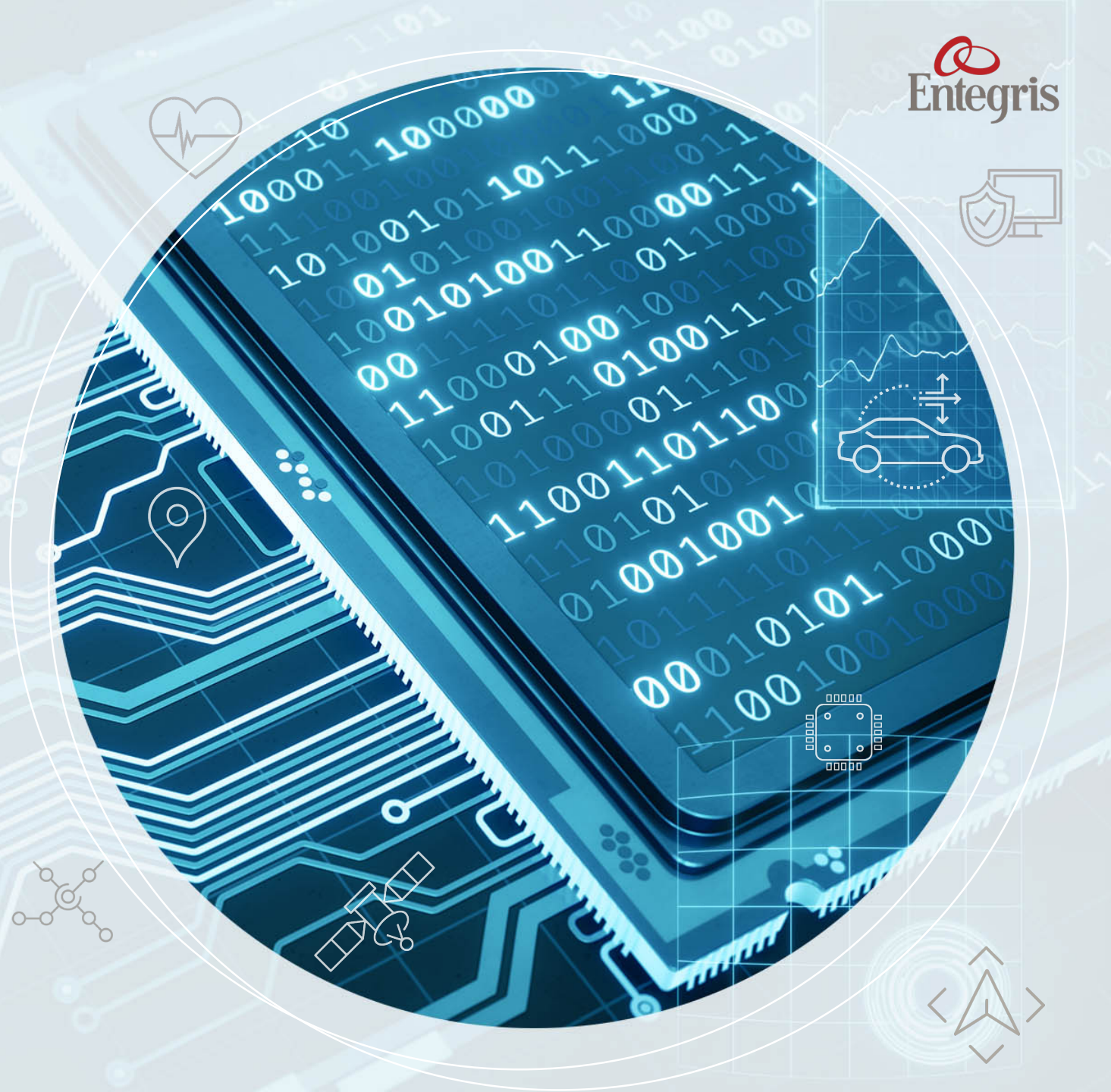


All key sectors including advanced/mainstream logic, DRAM, and 3D NAND benefit from the new growth drivers

Digital transformation
demands **higher
performance chips.**

New, purer materials are
needed to deliver high-yield
and long-term reliability

Holistic materials and handling
solutions ensures performance and
speed to yield

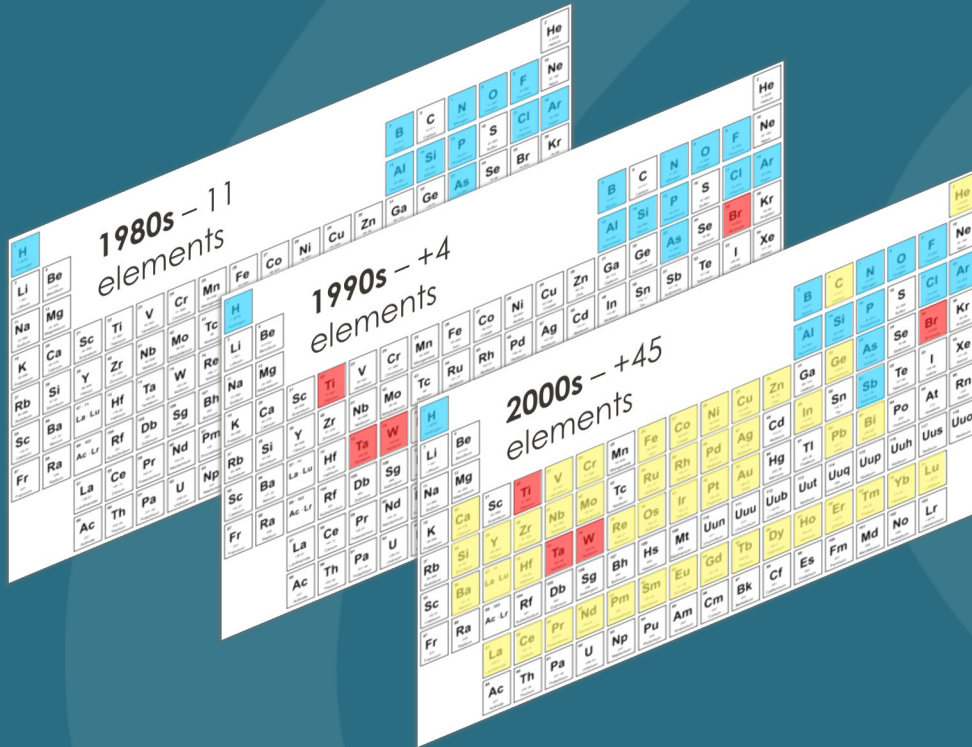


Increased importance of specialty materials – device performance.

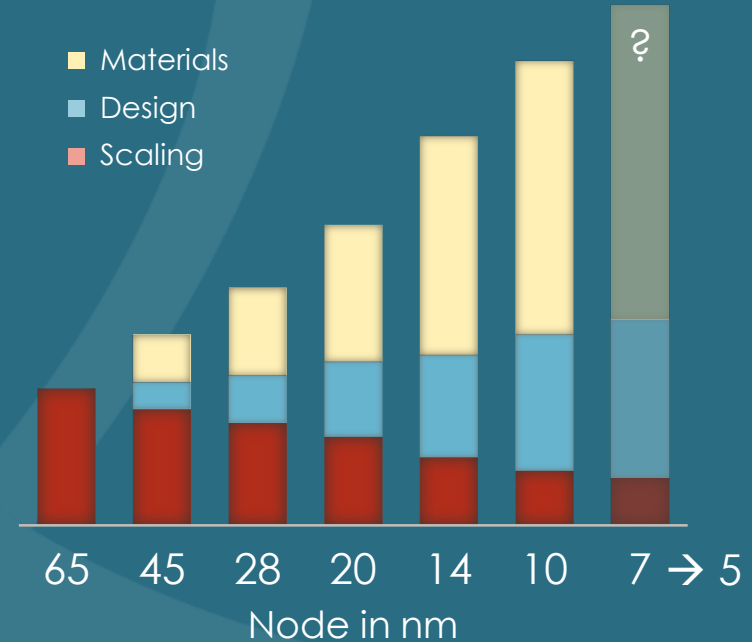
Integration of new material types is playing an increasing role in achieving device performance gains

Device Performance Drivers

Device performance and energy efficiency support emerging mobile markets and expanding data centers



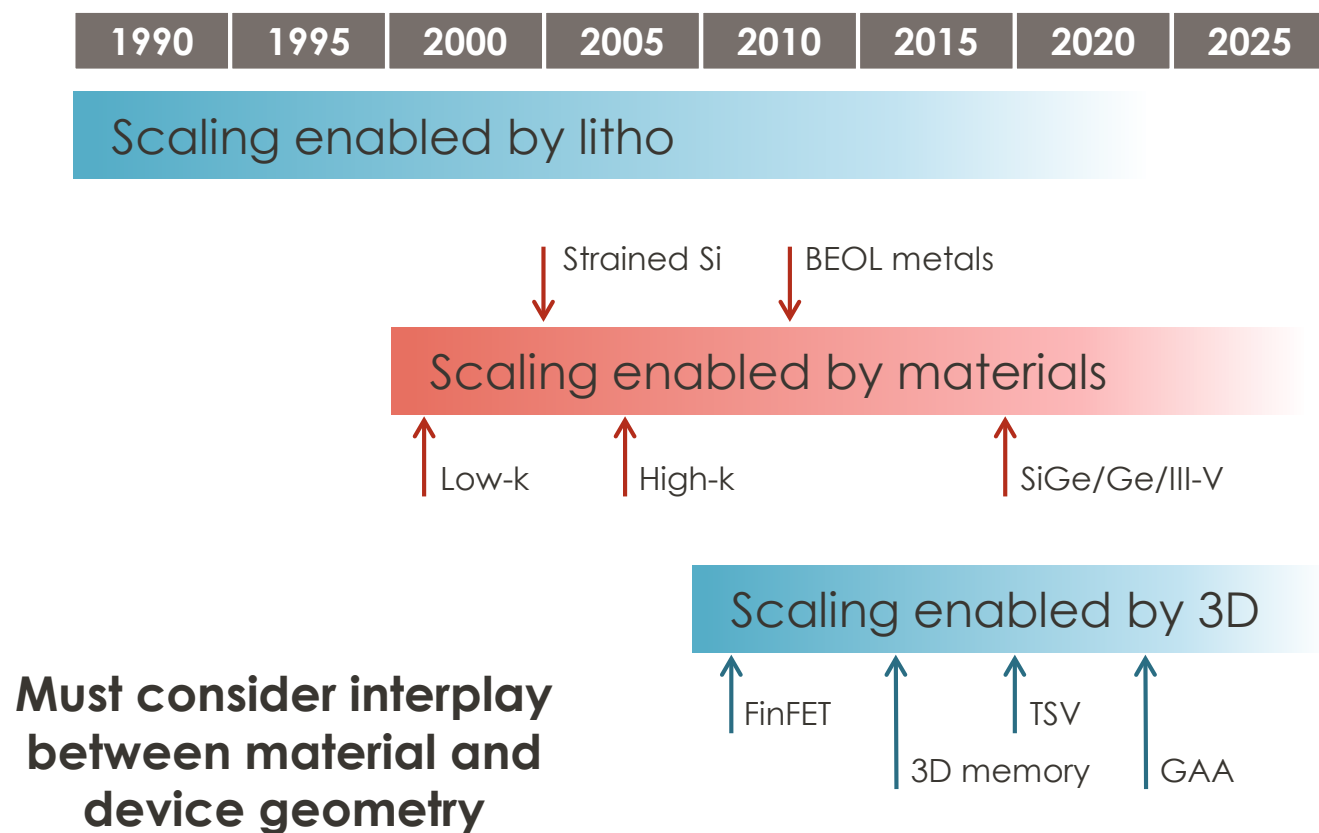
Relative Impact on Device Performance



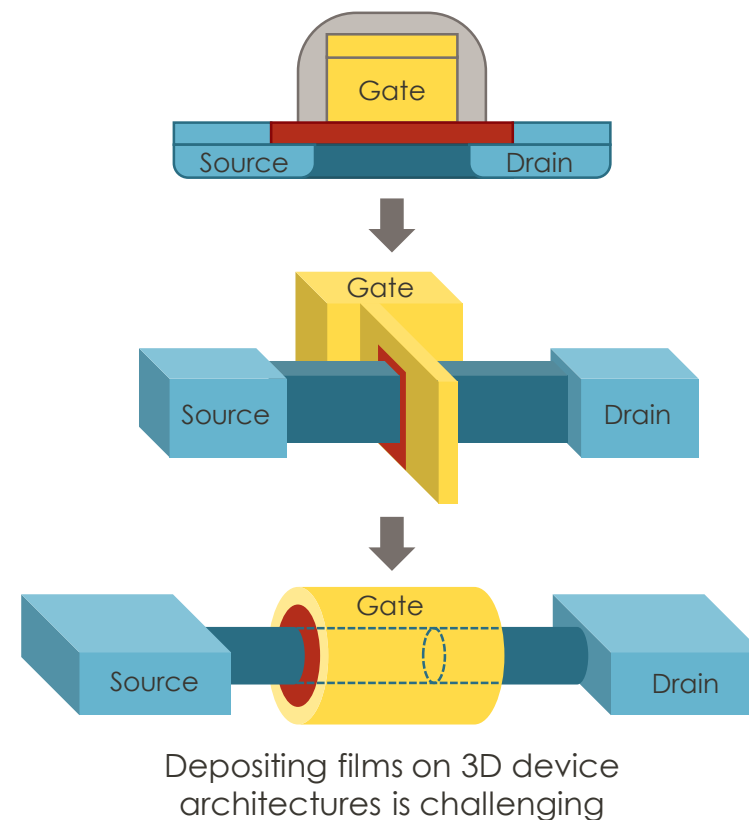
Materials are having a greater impact on semiconductor performance

Technical challenge: continuing Moore's law.

Performance scaling is increasingly enabled by new materials and 3D technologies



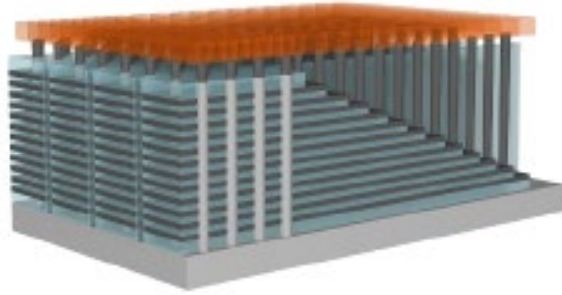
Moving from Planar to 3D



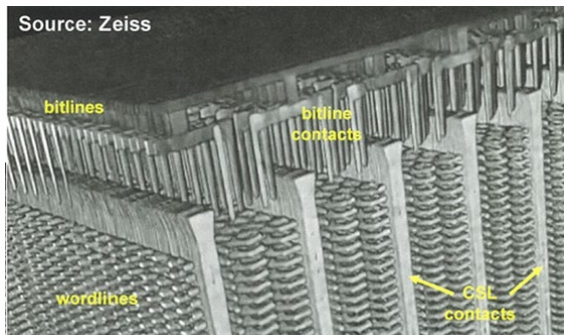
3D device architectures require increased conformality and selectivity for deposition processes

Process technology challenges for main semiconductor devices.

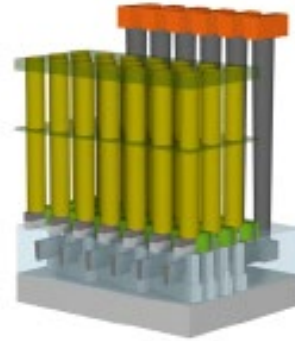
3D NAND



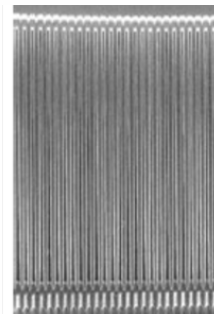
Multi-layering and productivity



DRAM

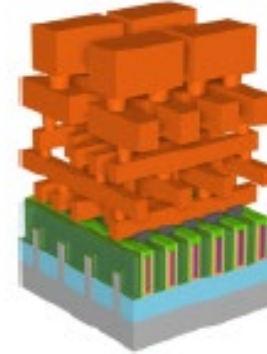


Enhancements from 1Y-1Z

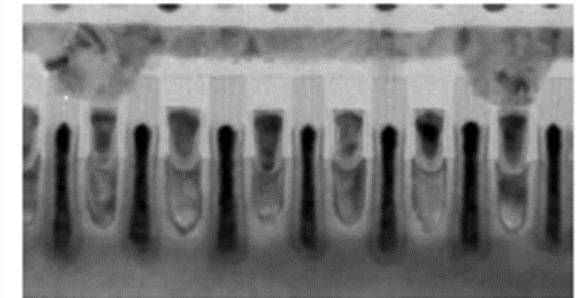


Capacitor array

Logic



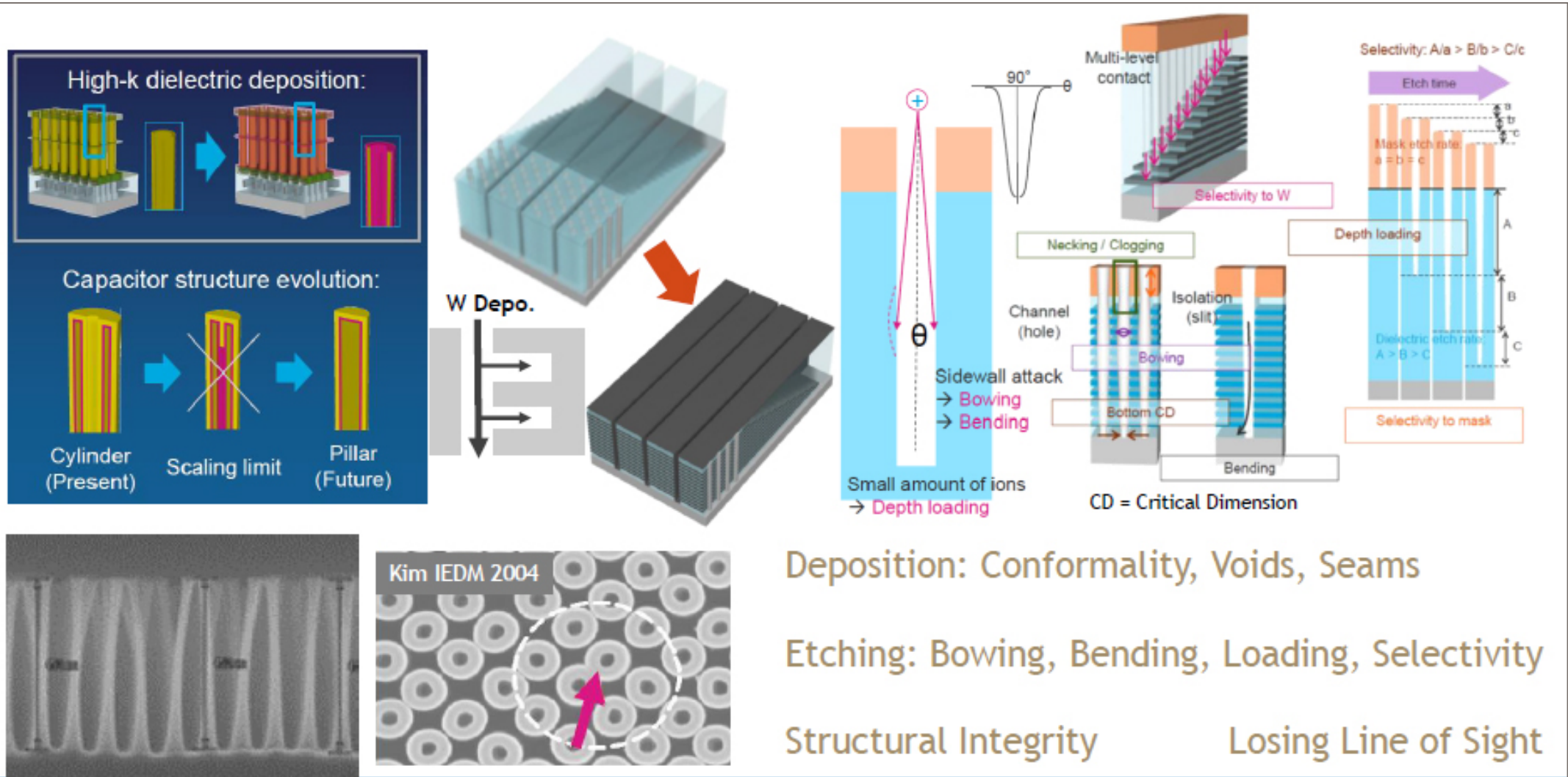
5 nm and 3 nm development



Intel 10 nm Co local interconnects and gate image
IEDM 2017 and IITC 2018

Continued scaling has driven the adoption of 3D architectures with increasing aspect ratio challenges. This trend places significant demands on materials needed to enable these devices.

Challenges from ever-increasing aspect ratios.



New materials on difficult geometries create complex challenges.

Increased Process Complexity

Change from 20 nm to 7 nm logic technology results in a **2x increase** in processing steps

Faster Cycle Time

Production ramp for 10 nm foundry wafers is **6 months faster** than 16 nm wafers

Advanced chips require **more materials** which means more process complexity and more challenging yield ramp

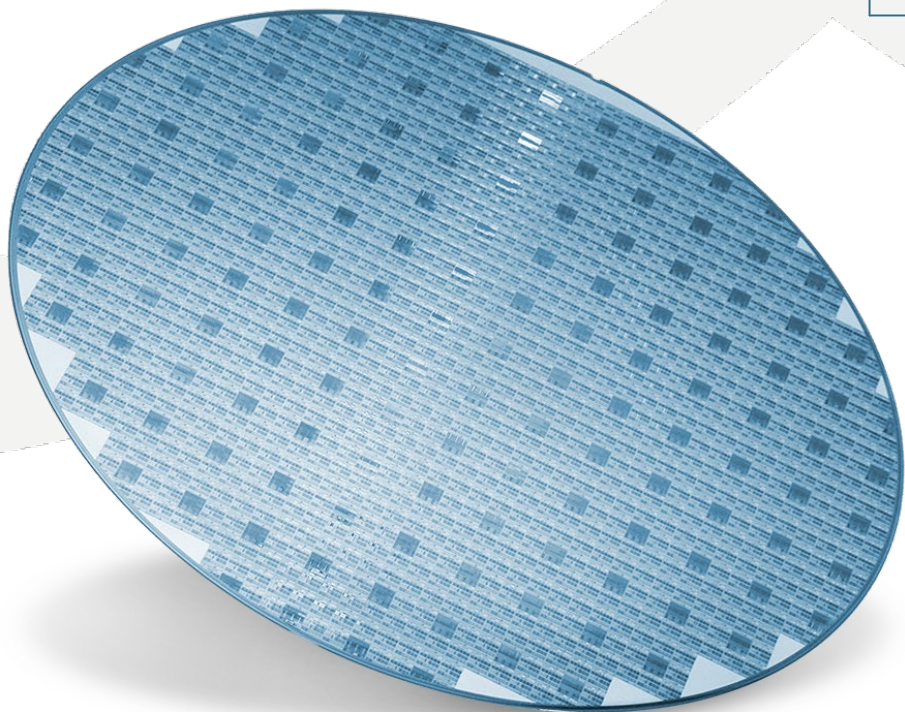
Still, “speed to yield” remains critical for timely technology introduction

Contamination control remains the largest challenge as wafer technology advances.

From 28 to 7 nm logic:

Metal impurity concentration limit is reduced **1000x**

Wafer killer particle size shrinks nearly **4x**



A **1% yield improvement** can mean:

\$150M/year net profit in a leading-edge logic fab¹

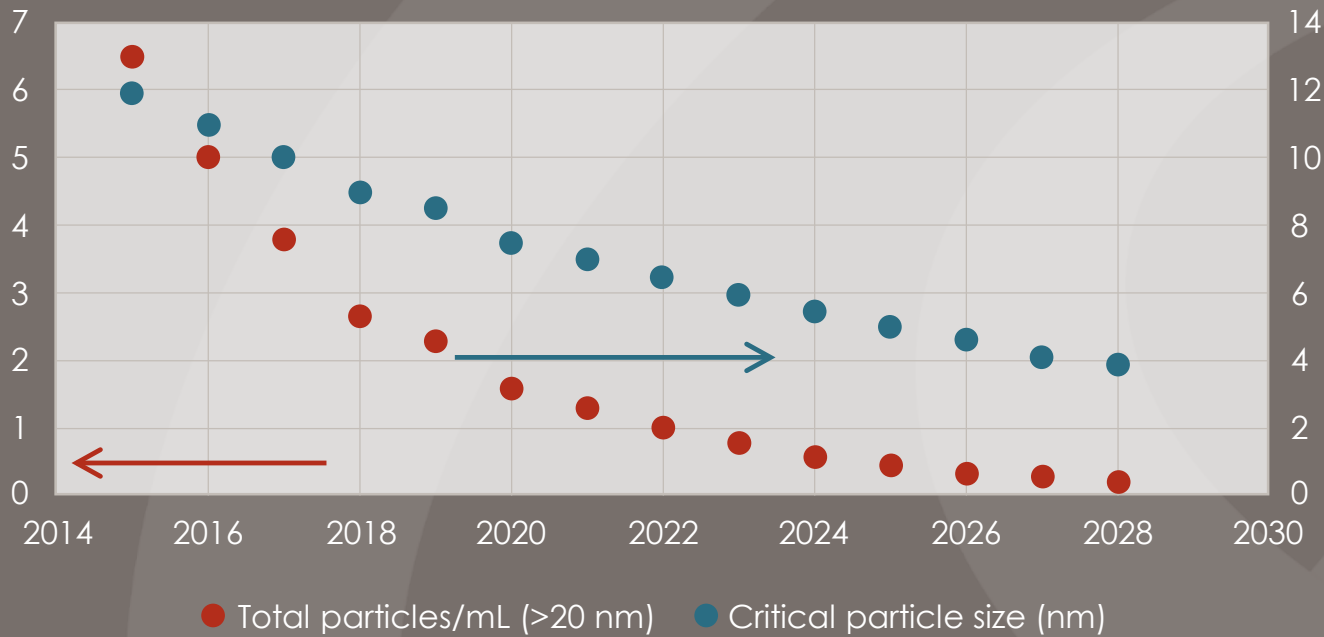
\$110M/year net profit for 3D NAND fabs²

¹Assumes 10 nm logic fab, 60K wafer starts per month

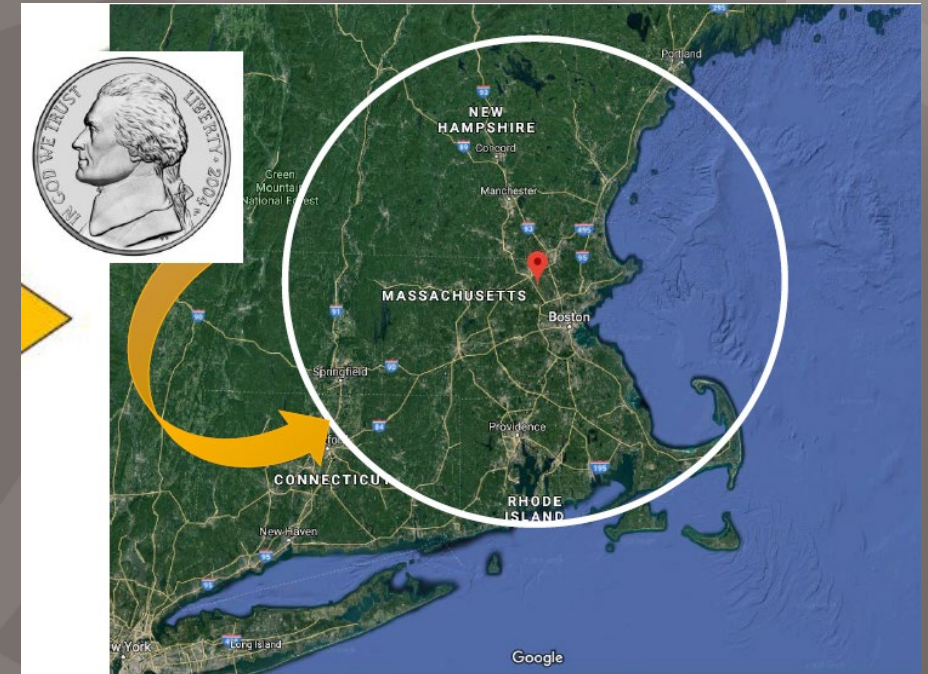
²Assumes 64 layer 3D NAND fab, 60K wafer starts per month

Material quality – particle control.

Total Particles and Critical Defect Size
2015 ITRS 2.0 Roadmap



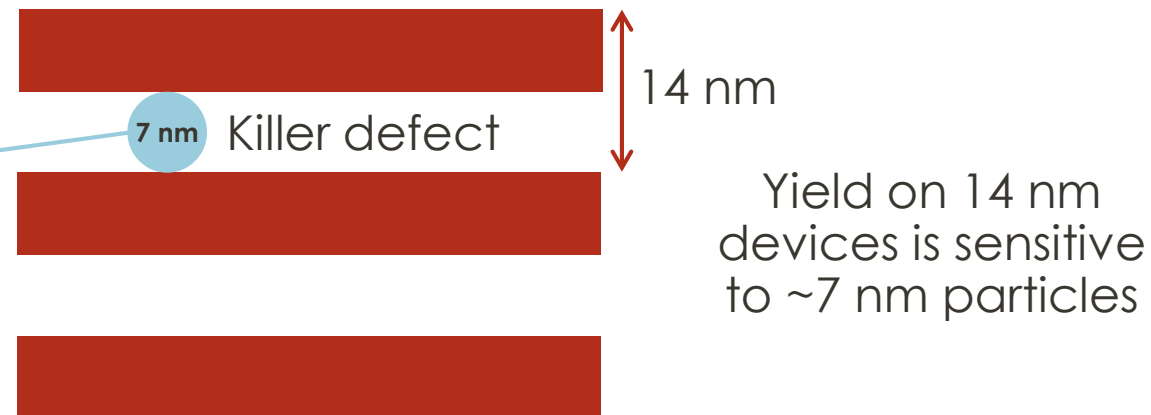
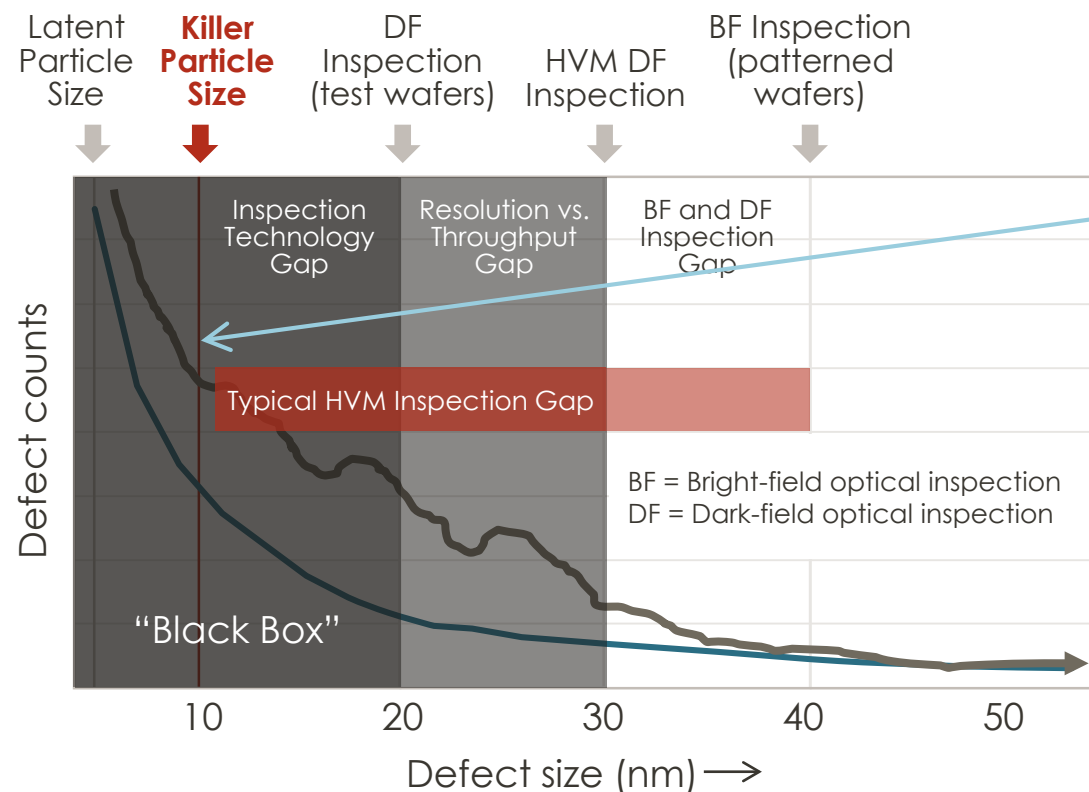
Today's Defect Density:
100 nickels in the area of a circle
187 mi in diameter



Source: KLA

Yield requirements drive lower particle counts at decreasing critical defect size

It's not easy to monitor sub-40 nm particles on wafers.

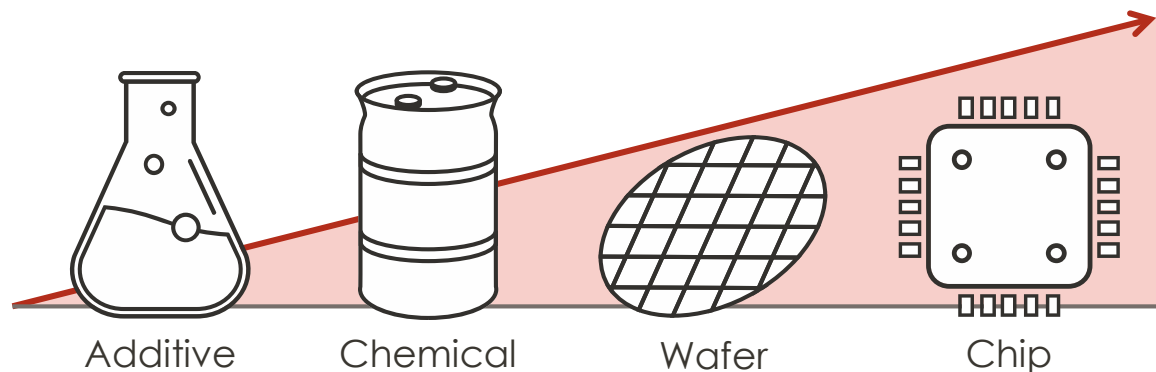


Customers increasingly demand most aggressive filtration capability as "insurance" against defects they cannot see

How to drive the best yield ramp within this black box? Need a holistic approach

- Materials cleanliness is a good starting point to prevent defects
- Complete solution includes filters, packaging, delivery and dispense, wafer environment (FOUP) and the data to validate effectiveness

Excursion control – increased materials purity.

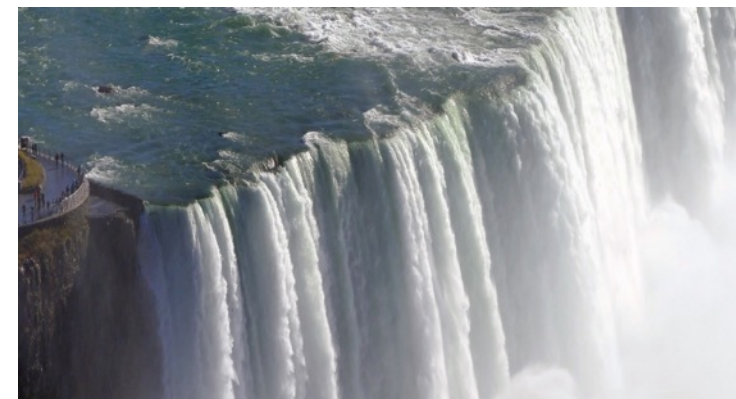


The impact of undetected, small problems early in the supply chain will increase exponentially:

- Contaminated raw material impacts mixed chemical quality
- Factory uses chemical for two-to-three weeks before detection
- 1000s of wafers at risk = Millions of die
- Market value (potential lost revenue and pure profit) = hundreds of \$M
- Additional supplier/IDM costs associated with potential chemical waste

IDMs want ZERO excursions → minimize financial impact

Characterization/controls must keep pace with process sensitivity

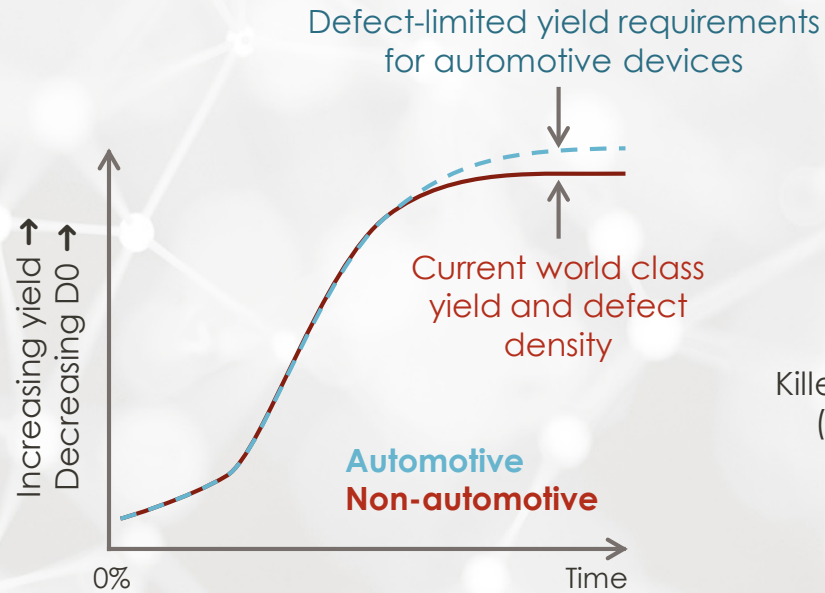


1 PPQ (parts per quadrillion)
equals one drop in all the water
that passes over Niagara Falls in **1 day**

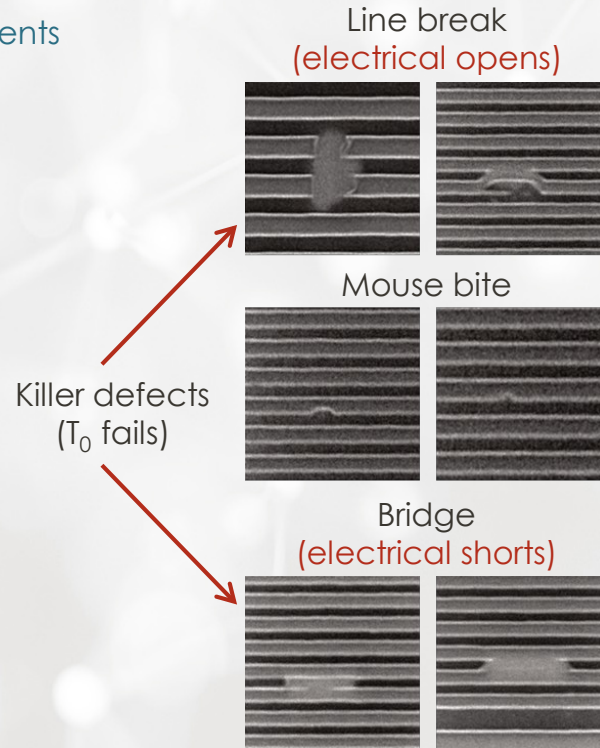


Not all defects are created equal.

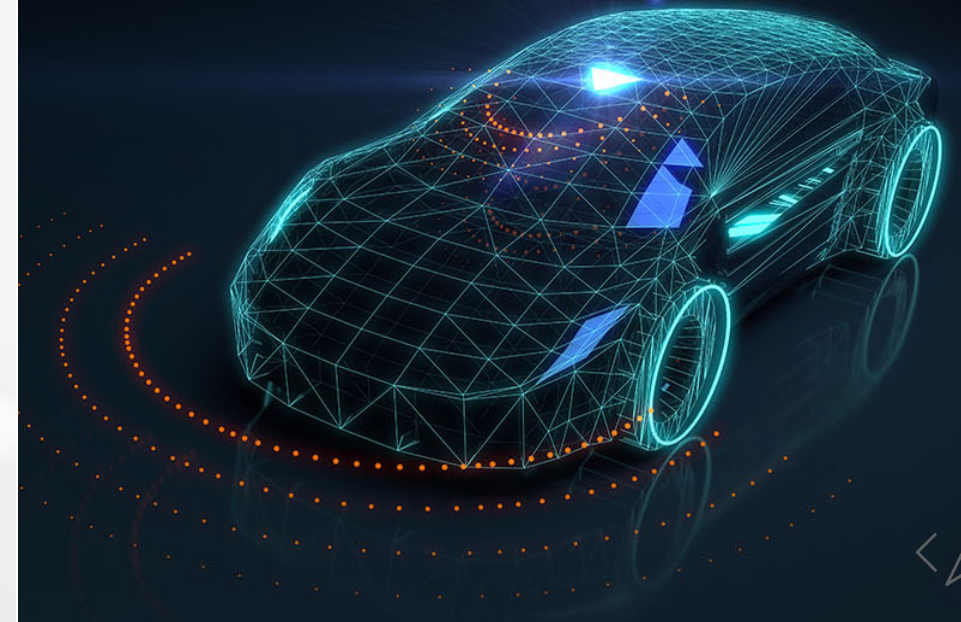
Latent defects and the automotive industry



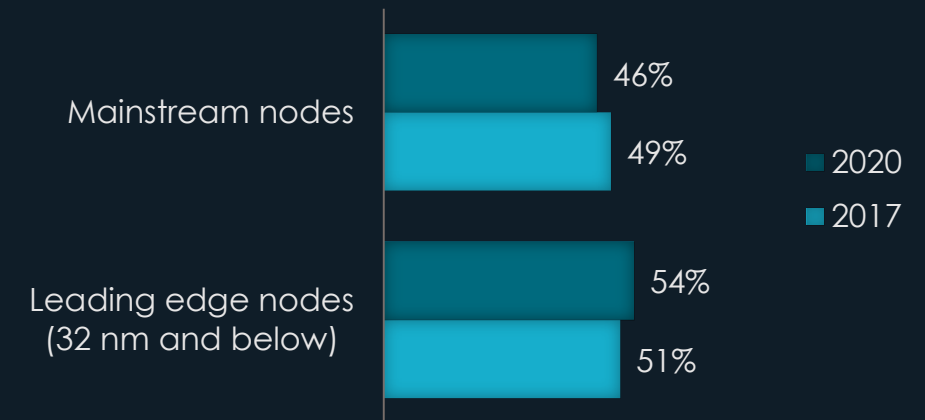
- **Electrical testing** – intended to detect defective units before release into the field
- **Burn-in** – used to accelerate failure of marginally defective components (latent defects)
- **Failure analysis** – highlights defect sources and process marginalities



Increased reliability requirements call for improved defect control

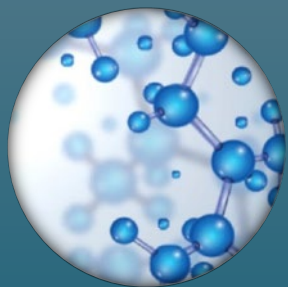


Leading Edge vs. Mainstream Nodes as Total WW Capacity



Source: Gartner

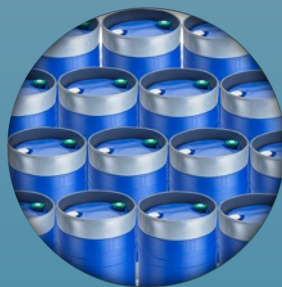
Contamination control over the whole ecosystem.



Raw
Materials



Chemical
Production



Packaging
Shipment



Bulk Delivery



Point of Use

← Key enablers: metrology and advanced filtration and purification →

Holistic solutions require broad capabilities.

Specialty Chemicals & Engineered Materials



- SDS/VAC delivered gases
- Post Etch/CMP cleans
- Plating and CMP components
- Advanced deposition materials
- Graphite and SiC
- Specialty coatings

Microcontamination Control



- Liquid filters and purifiers
- Gas filters/diffusers/purifiers
- Airborne molecular contamination control

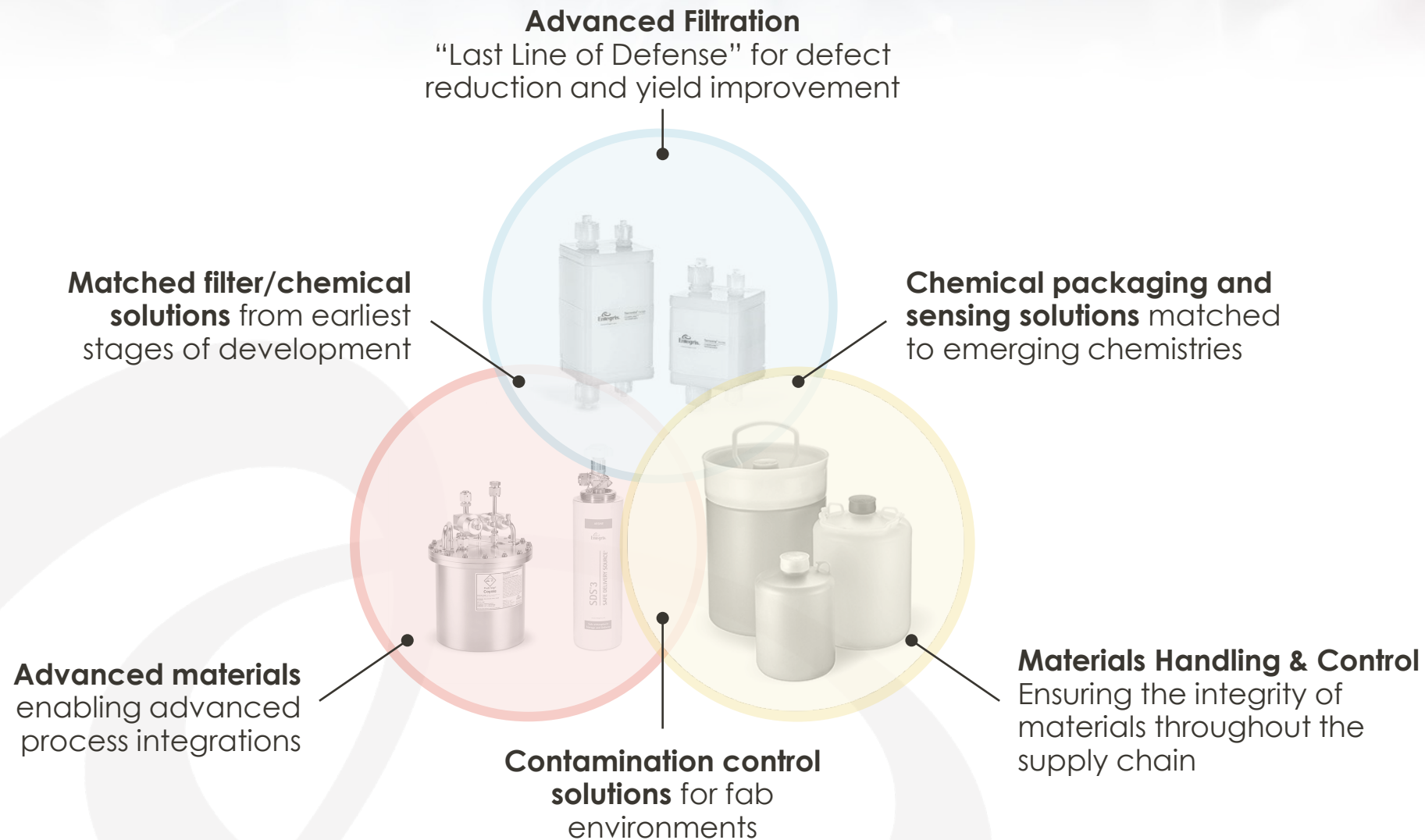
Advanced Materials Handling



- Microenvironments
- Fluid handling
- Sensing and control
- Liquid packaging

Technical depth within each category allows an understanding of how to put the pieces together

Value is derived from co-optimized solutions for specific needs.



Holistic Solutions: Case Studies



Solid precursor delivery and contamination control.

Technical challenge

Solid precursors for ALD/CVD: stable mass flux, low vapor pressure, and limited thermal stability

Contamination in deposited film from precursor/vessel interaction

Solution

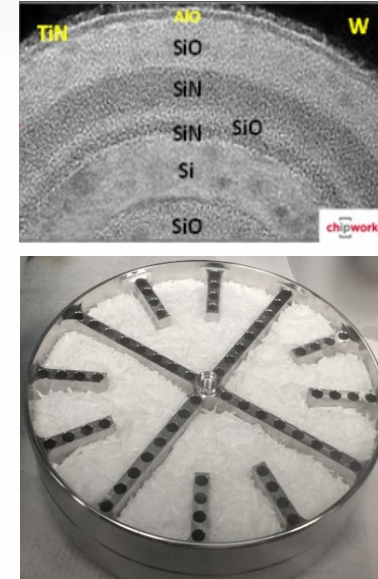
High-purity precursor and enabling delivery vessel

Protective coating of vessel interior and tool components

In-line filtration and coatings on filter apparatus

Benefits

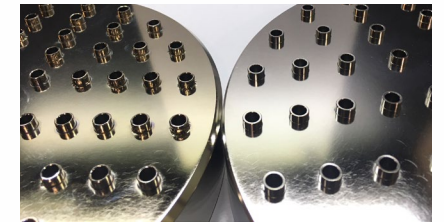
Technical depth and product breadth enable holistic solution to advanced node problem



ProE-Vap® solid delivery vessel



GateKeeper® GPU purifier and high-temp PTFE filter



Corrosion-resistant coatings protect ProE-Vap trays

Co-optimized wet chemistry and filtration.

Technical challenge

Removal of nitride layers in high aspect ratio 3D NAND structure requires highly selective etch chemistry

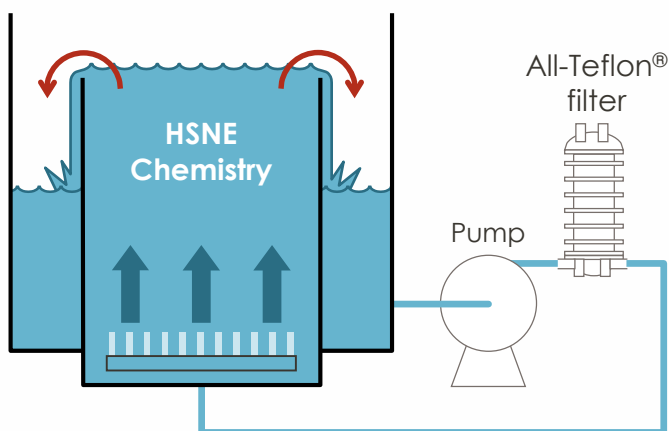
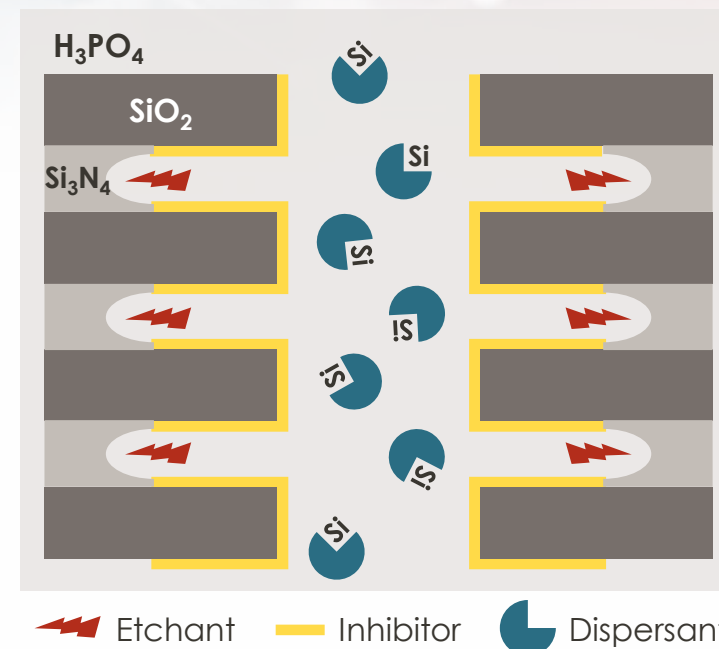
Advanced filtration solutions required for high temperature and flow application without affecting additives in chemical formulation

Solution

Highly selective nitride etch chemistry matched with surface-modified chemical filter

Benefits

Stable etch chemistry enabled by surface-modified filtration technology



Effect of unmatched filters on etch formulation



Non-optimized filter can remove critical components of formulation and affect etch performance

Enabling yield in the CMP ecosystem.

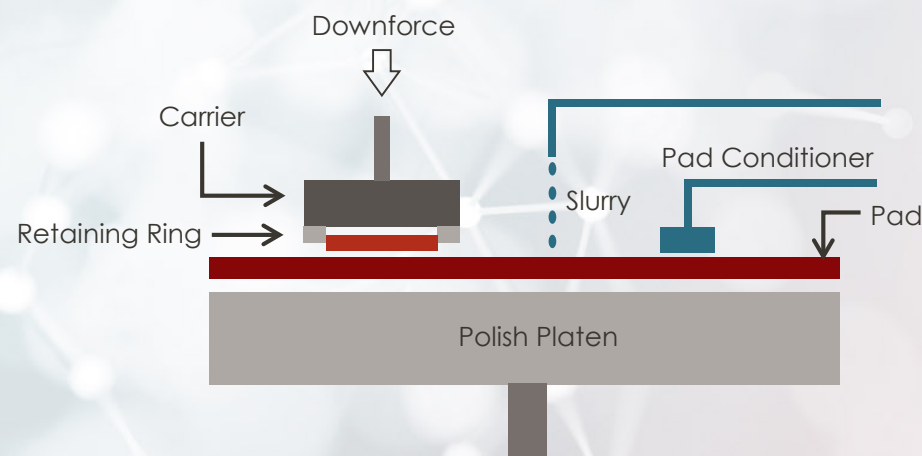
Entegris Everywhere

CMP Equipment



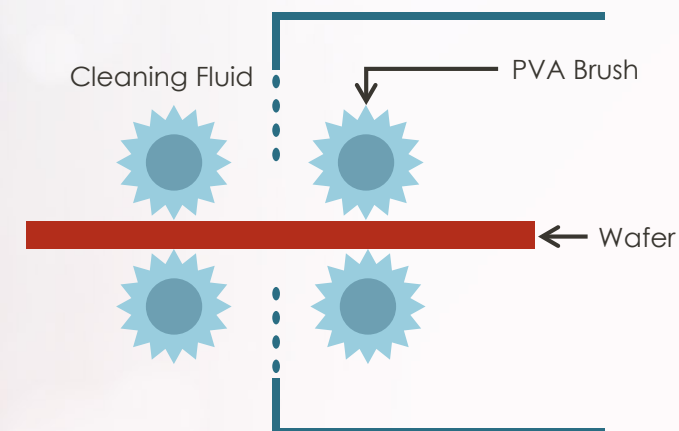
Fluid flow control
Fluid packaging
Slurry monitoring and control (PSS)

CMP Process



Slurry filtration
Pad conditioning

Post CMP Clean



pCMP clean brush
pCMP clean formulation
pCMP clean filtration

Higher yields.

Better performance.

Reliability.

What end users expect

**Holistic solutions should enable superior
total cost of ownership (TCO)**

Improvements in reliability, un-planned downtime, life-expectance, scrap, ease of integration increase **overall value and ROI**

Customer perspective.

Materials will play an increasing role in achieving device performance gains for new transistor architectures

Process complexity will be a headwind to introducing new process nodes placing a premium on time-to-yield

Materials suppliers with holistic solutions that ensure materials integrity across the entire supply chain are best positioned to meet future defectivity requirements

Broadly capable materials suppliers are best positioned to help achieve time-to-yield.

No matter what shift in technology comes next...

Entegris is committed to adaptive innovation.



Materials Innovation | Holistic Solutions | Strategic Partnerships

“The best way to predict the future is to invent it.” – Alan Kay, 1940

Thank you!

A graphic consisting of a white rectangular box with a white border and a white tail pointing towards the bottom right. Inside the box, the text "Q&A" is written in a large, black, sans-serif font. The background of the slide features silhouettes of five people in business attire standing in a circle, with a city skyline and a body of water visible in the background. A large, faint, light blue circular graphic is overlaid on the silhouettes.

Q&A