9 megatrends that are shaping the industry.

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.

Materials are having a greater impact on semiconductor performance.

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

Relative Impact on Device Performance

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<th>Node in nm</th>
<th>65</th>
<th>45</th>
<th>28</th>
<th>20</th>
<th>14</th>
<th>10</th>
<th>7 → 5</th>
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Source: Entegris estimates

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

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**Scaling enabled by litho**
- Strained Si
- BEOL metals

**Scaling enabled by materials**
- Low-k
- High-k
- SiGe/Ge/III-V

**Scaling enabled by 3D**
- FinFET
- TSV
- 3D memory
- GAA

Moving from Planar to 3D

Depositing films on 3D device architectures is challenging.

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

Must consider interplay between material and device geometry.
Process technology challenges for main semiconductor devices.

3D NAND

Multi-layering and productivity

DRAM

Enhancements from 1Y–1Z

Logic

5 nm and 3 nm development

Capacitor array

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.

Deposition: Conformality, Voids, Seams

Etching: Bowing, Bending, Loading, Selectivity

Structural Integrity Losing Line of Sight

Symposia on VLSI Technology and Circuits Sekiguchi SSDM Short Course 2018
New materials on difficult geometries create complex challenges.

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.

**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.
Contamination control remains the largest challenge as wafer technology advances.

From 28 to 7 nm logic:
- Wafer killer particle size shrinks nearly 4x
- Metal impurity concentration limit is reduced 1000x

A 1% yield improvement can mean:
- $150M/year net profit in a leading-edge logic fab\(^1\)
- $110M/year net profit for 3D NAND fabs\(^2\)

\(^1\) Assumes 10 nm logic fab, 60K wafer starts per month
\(^2\) Assumes 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

Yield requirements drive lower particle counts at decreasing critical defect size

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

Source: KLA
It’s not easy to monitor sub-40 nm particles on wafers.

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

Yield on 14 nm devices is sensitive to ~7 nm particles

Customers increasingly demand most aggressive filtration capability as “insurance” against defects they cannot see
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
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**

Source: Gartner
Contamination control over the whole ecosystem.

Key enablers: metrology and advanced filtration and purification
Holistic solutions require broad capabilities.

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.

Advanced Filtration
“Last Line of Defense” for defect reduction and yield improvement

Matched filter/chemical solutions from earliest stages of development

Chemical packaging and sensing solutions matched to emerging chemistries

Advanced materials enabling advanced process integrations

Contamination control solutions for fab environments

Materials Handling & Control Ensuring the integrity of materials throughout the supply chain
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

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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**
- Downforce
- Carrier
- Retaining Ring
- Slurry filtration
- Pad conditioning
- Pad Conditioner

**Post CMP Clean**
- Cleaning Fluid
- PVA Brush
- Wafer
- pCMP clean brush
- pCMP clean formulation
- pCMP clean filtration
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


What end users expect
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.

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

Q&A