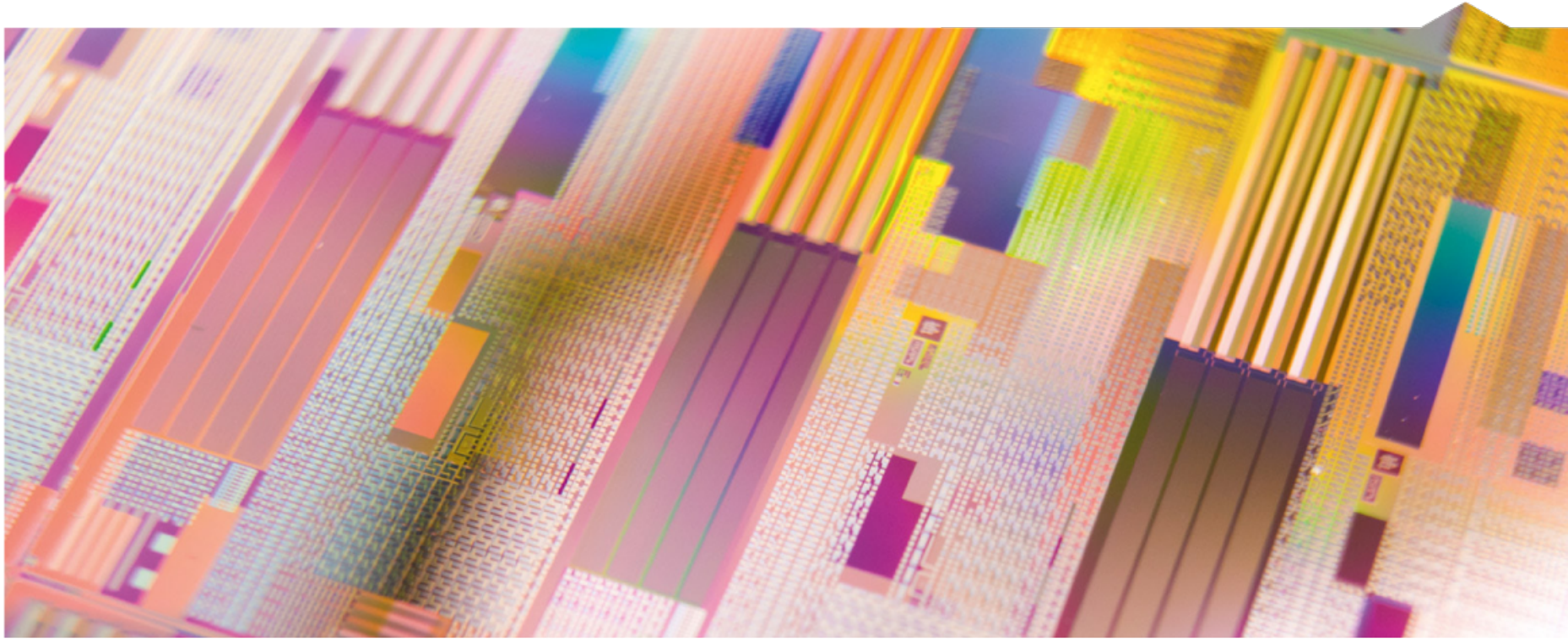
DRIVE INNOVATION · DELIVER EXCELLENCE >

ASM



ALD MATERIALS INTEGRATION CHALLENGES

GLEN WILK

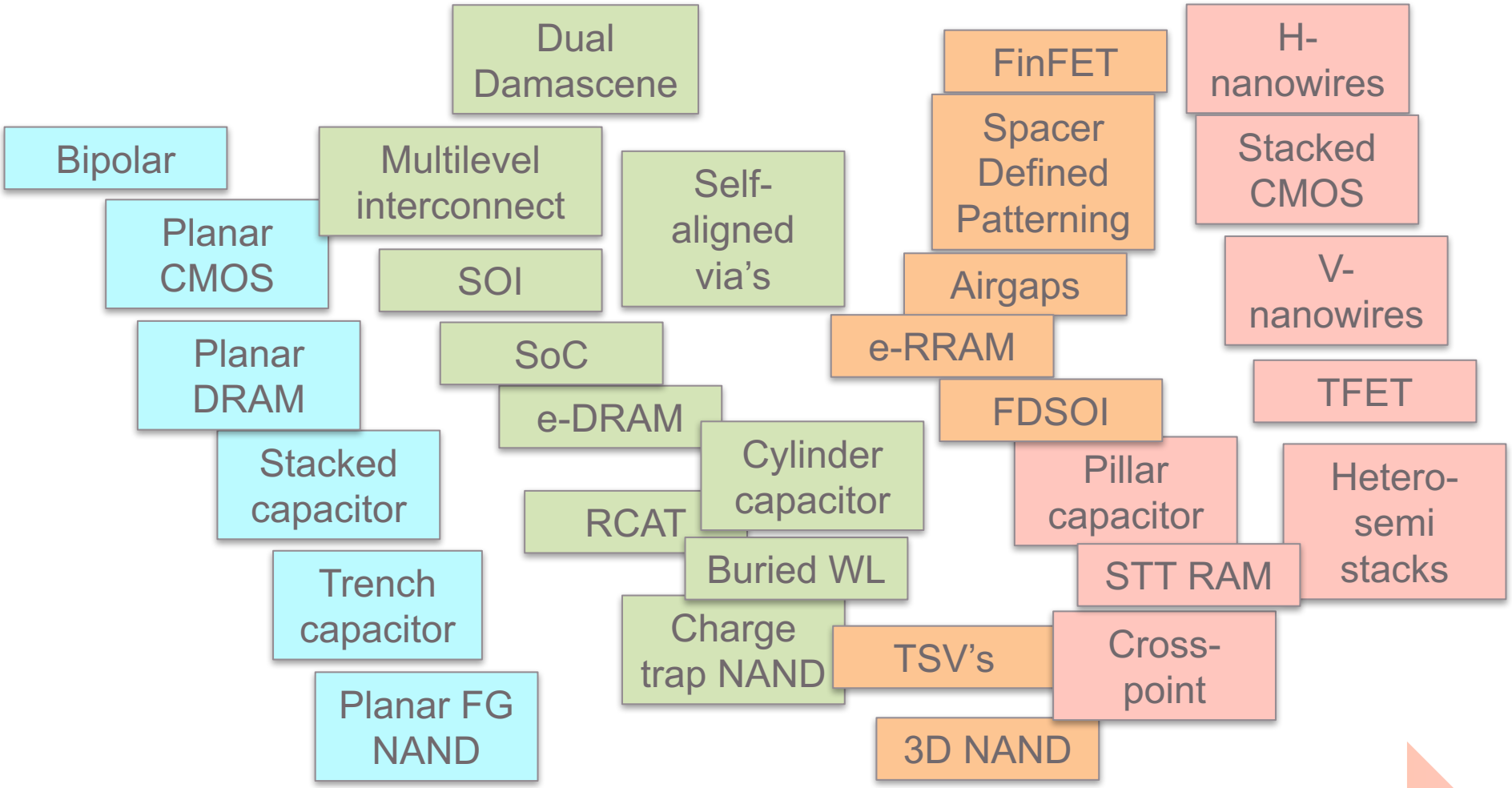
OUTLINE

- Industry Trends for Materials and Architectures
- Examples of materials innovations
  - High-k and metal gate
  - Patterning materials
  - New spacer materials
  - Low thermal budget processes
- Needs from Chemical Suppliers

INDUSTRY TRENDS

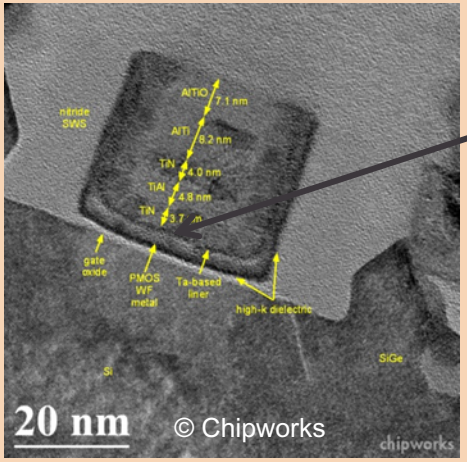
DRIVE INNOVATION • DELIVER EXCELLENCE

ARCHITECTURAL INNOVATIONS: MOORE'S LAW ENABLERS



INDUSTRY TRENDS IN LOGIC

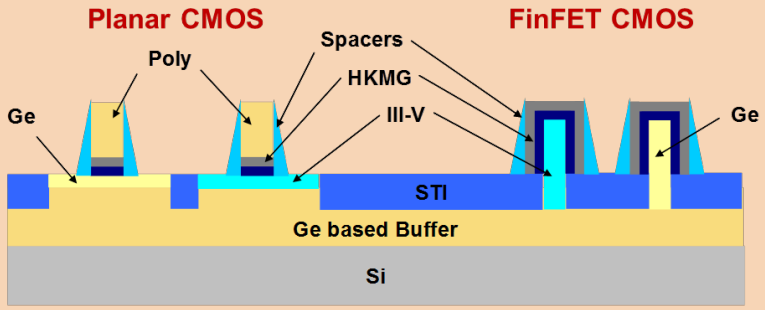
Higher Capacitance, Lower Leakage



High-k and Metal Gates

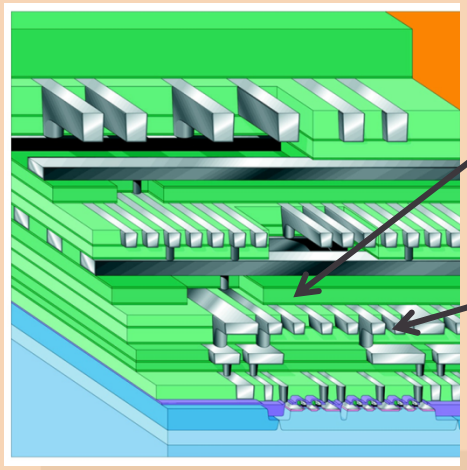
DRAM, RF, decoupling capacitors

Higher Mobility, Lower Resistance



Strain and new Channel Materials
New metal contacts

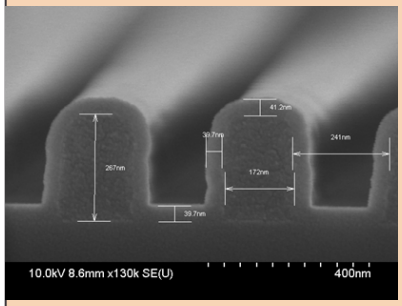
Less Cross Talk, Faster Interconnect



(Porous) Low-k Materials

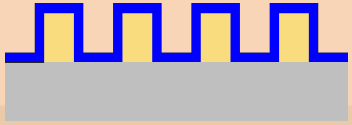
Improved Metals

Smaller Feature Sizes

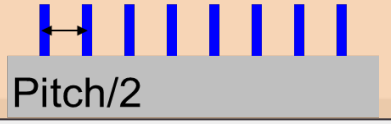


-EUV delays led to more double patterning (SDDP/SDQP)
-EUV will enable many new materials

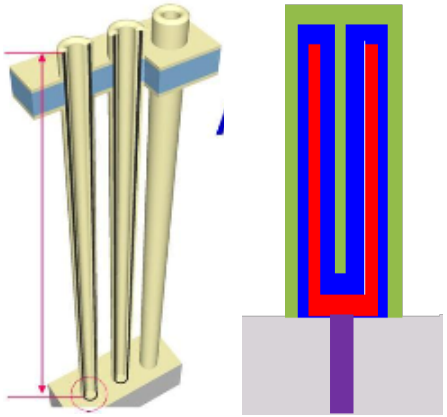
Conformal SiO_2



Anisotropic Etch



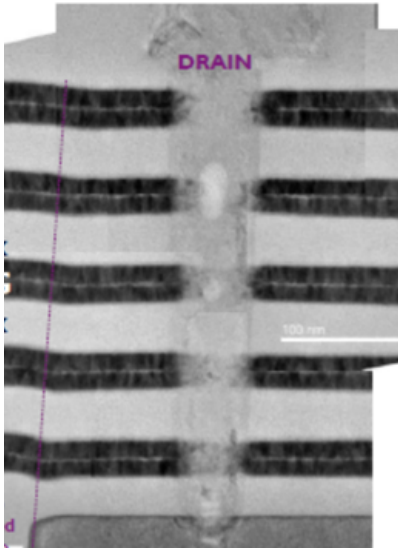
INDUSTRY TRENDS IN MEMORY



DRAM cell

New materials:
High WF metal for TE and HK in BO
CT layers

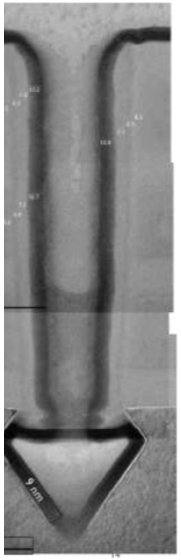
Requirements:
Thickness<5nm
MG WF>4.8eV



Vertical NAND

New Materials:
Low R metals

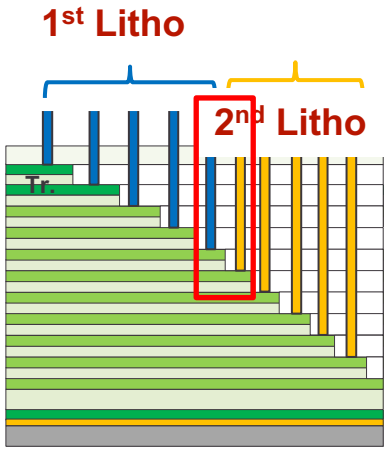
Requirements:
R<100uOhm*cm
Fluorine free



VNAND high-mobility channels

New Materials:
ALD III-V
Conductive oxides

Requirements:
Thickness<10nm
AR>50
Thermal stab 800C
Conformality: 95%



Staircase

New Materials:
Selective ALD in staircase
ALD a-C protective fill layer
Resist hardening

Source: Chipworks

MATERIALS INNOVATIONS

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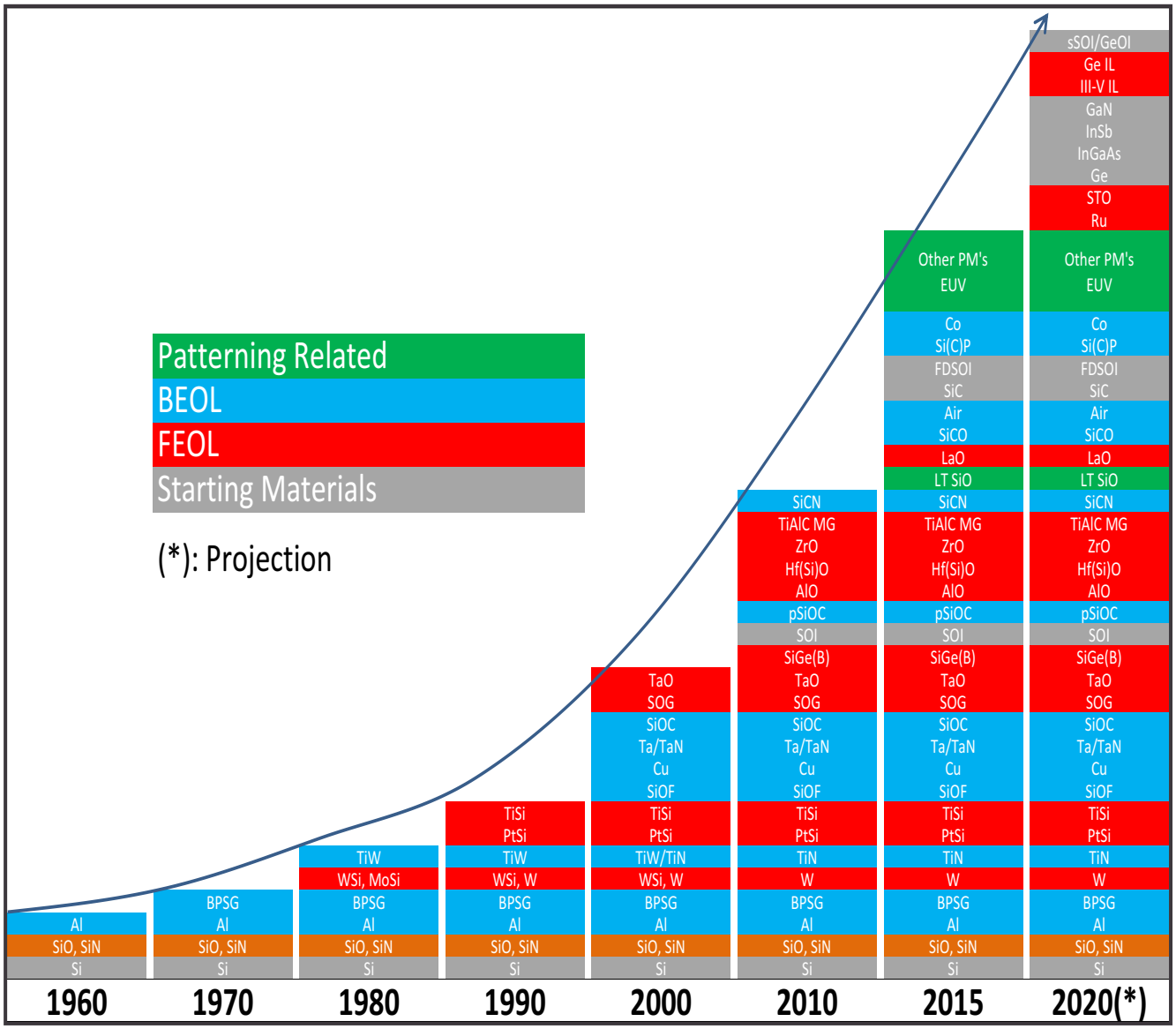
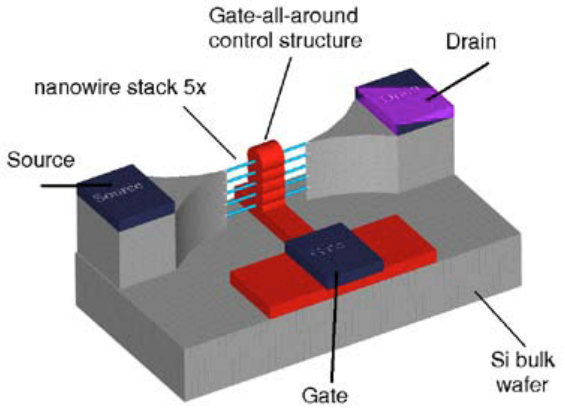
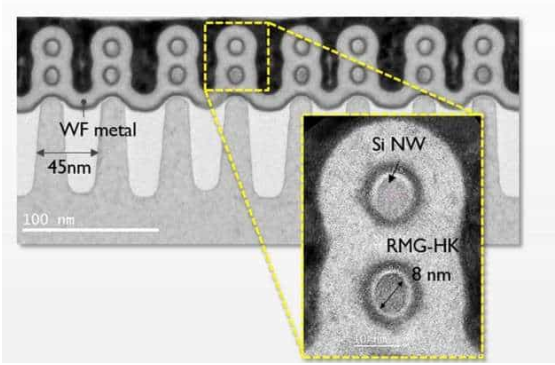
NEW MATERIALS: MOORE'S LAW ENABLERS



THERMAL ALD SOLUTIONS CRITICAL FOR 3D STRUCTURES



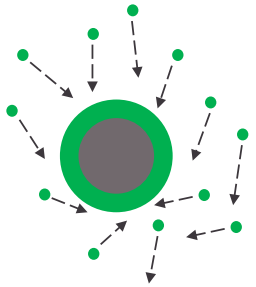
Source: SemiEngineering



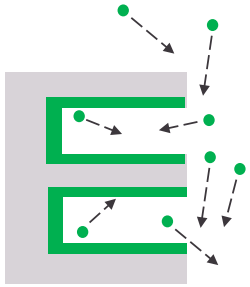
Source: IMEC

- **Move to 3D devices necessitates the use of pure thermal ALD techniques**
- **Lower thermal budgets for ALD and PEALD**

Thermal ALD

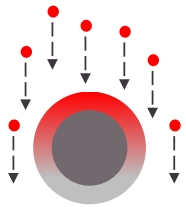


Stoichiometric film regardless of directionality

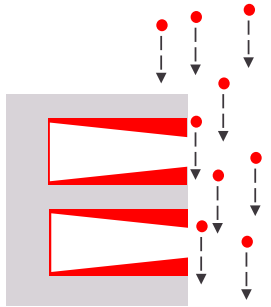


Near perfect step coverage in deep and re-entrant structures

Plasma ALD



Directional nature of reactants results in non-uniform composition

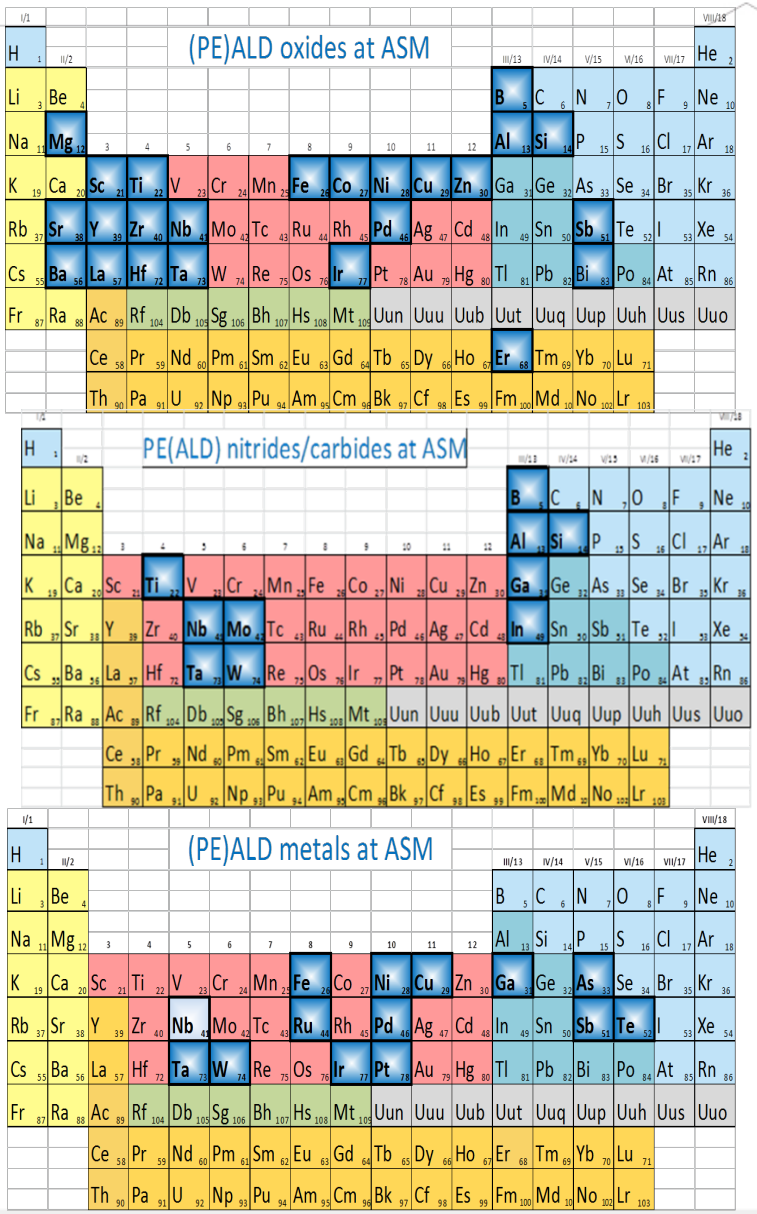


Step coverage limited (especially in re-entrant structures)

PROCESS INNOVATIONS: MOORE'S LAW ENABLERS

- **Thermal and plasma-enhanced ALD are materials enablers:**
  - High-k capacitor
  - High-k gate dielectric
  - Metal gate
  - Metal Nitrides (HfN)
  - Low-T oxide
  - Low-T nitride…

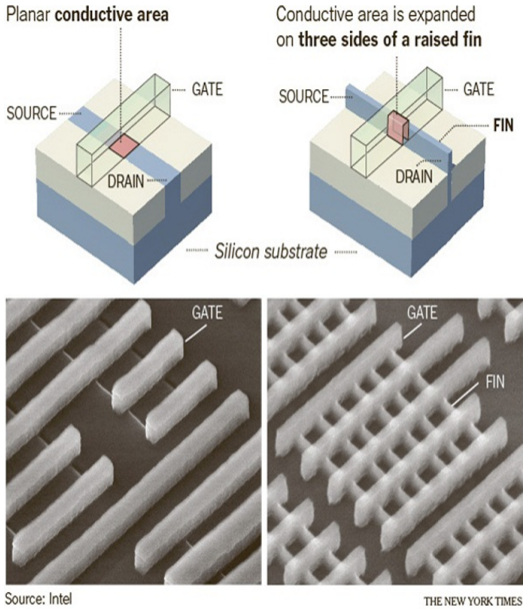
Made by ASM

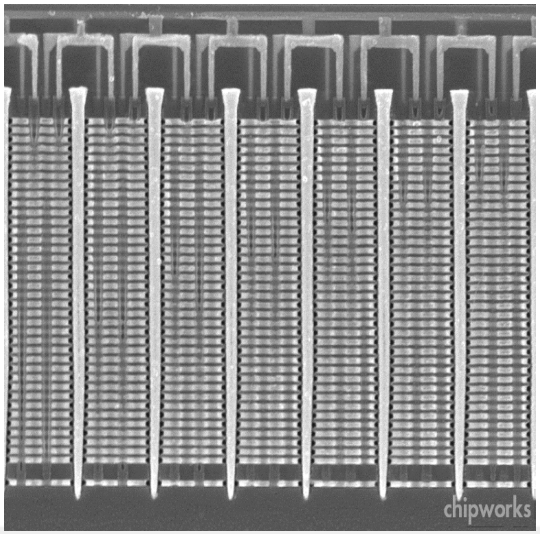


PROCESS INNOVATIONS: ALD AND PEALD

- **Atomic Layer Deposition separates reactive precursors in time (or space), and grows materials one 'atomic' layer at a time**
  - Superb control of uniformity, conformality, quality, and composition over any topography
  - Plasma Enhanced ALD provides high quality materials at lower temperatures
  - Need many etch selective materials with wide range of film properties and compositions

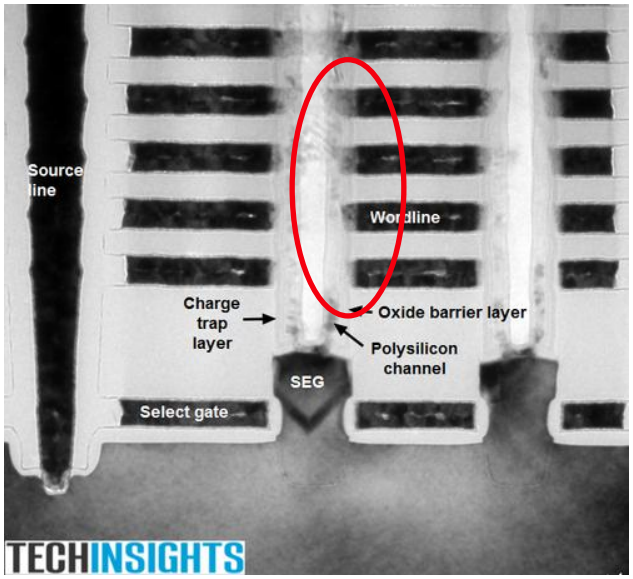
- **ALD and PEALD are <u>architecture enablers</u>: High Aspect Ratio structures, FinFET, double patterning, VNAND,…**

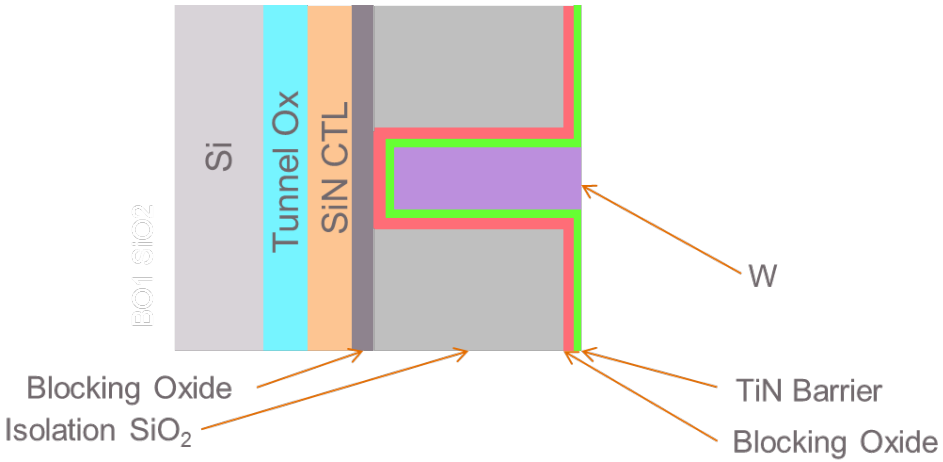




Right: NY Times 2011; http://electroiq.com/chipworks_real_chips_blog/2014/08/04/

METAL FOR VNAND WL FOR VERTICAL & LATERAL PITCH SCALING





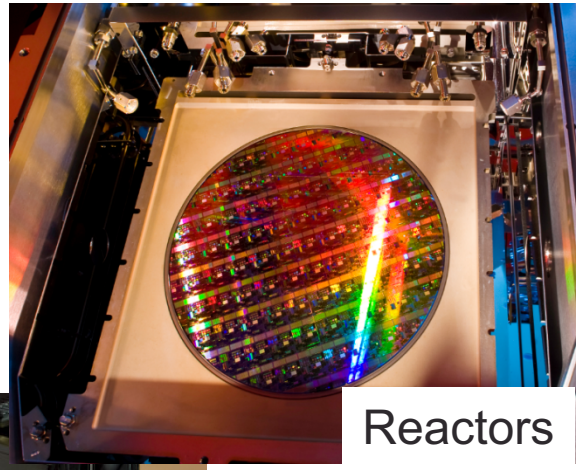
To enable vertical scaling of word line

- Development of ALD TiN with fast-closing layer < 15A
- Development of F-free ALD processes
- New precursors

CRITICAL ALD SUPPLY CHAIN COMPONENTS

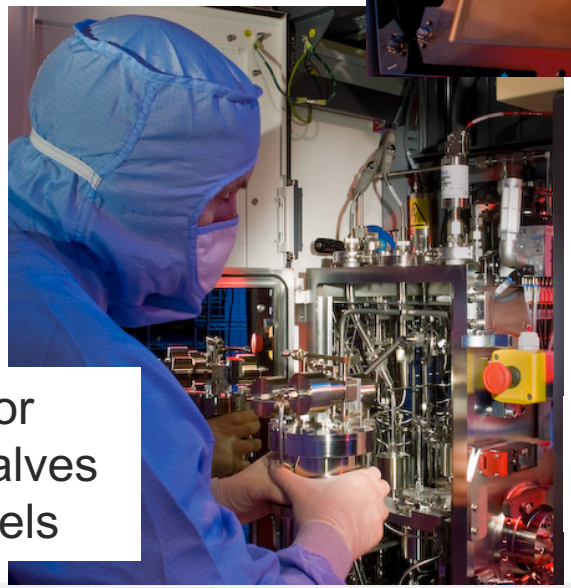
Fundamental Capability → Process Performance → Productivity → Integrated Process → Final Product Capability

Precursors



Reactors

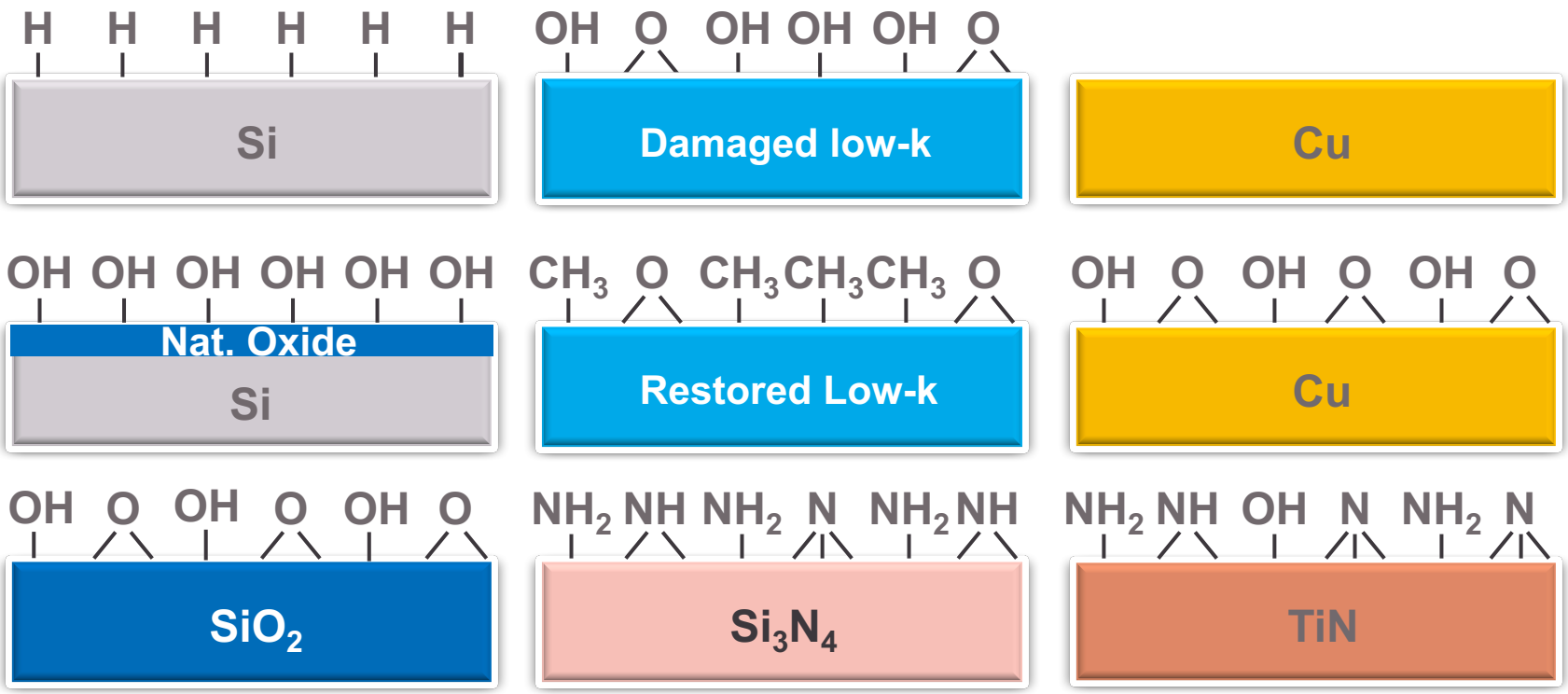
High productivity tools



Precursor Delivery, Valves and Vessels

Fab facilities, pumps & abatement

WHAT'S NEXT IN PROCESS INNOVATIONS?



- **The surface sensitivity of ALD and CVD may be ideal to create selective deposition**
  - Many potential applications exist in memory, logic, interconnect, and patterning
  - Building templated self-aligned structures: reduction of overlay requirements
- **Strong need for many variations of selective ALD: Metal on Metal, Dielectric on Dielectric, etc.**
- **Reversing the reaction to highly selective Atomic Layer Etching**

LOW THERMAL BUDGET PROCESSES

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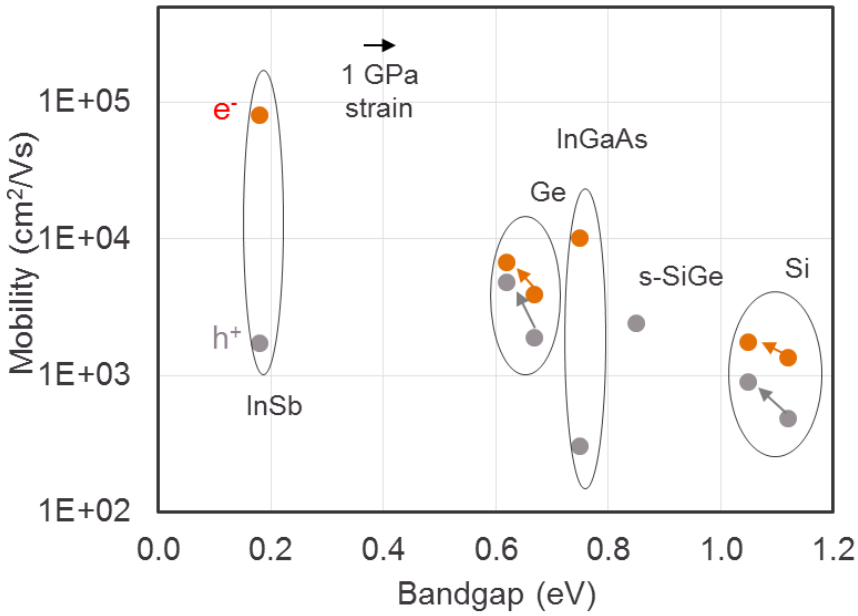
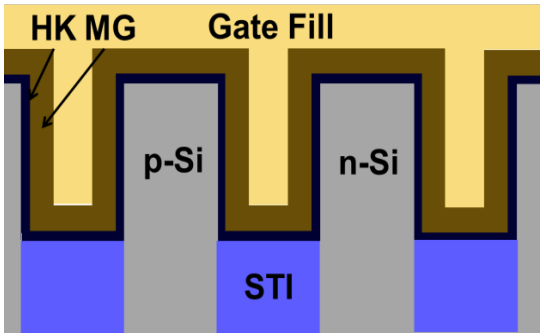
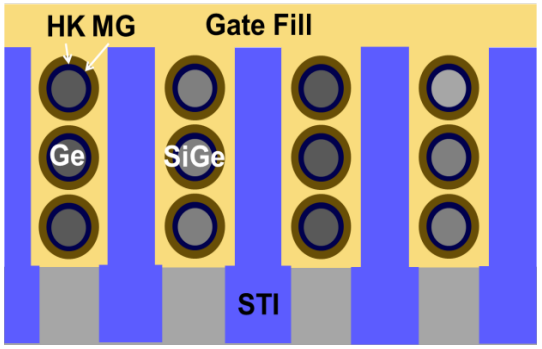
HIGH MOBILITY CHANNEL MATERIALS

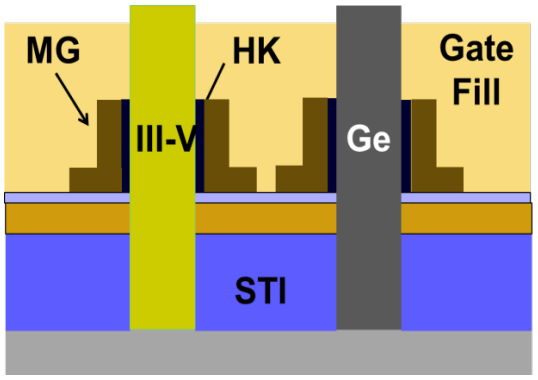
- Voltage scaling requires high mobility channel materials with proper bandgap
- Introduction will probably be simultaneous with architecture change to nanowires
- Epitaxy and ALD will be enabling deposition technologies



2011







~2021

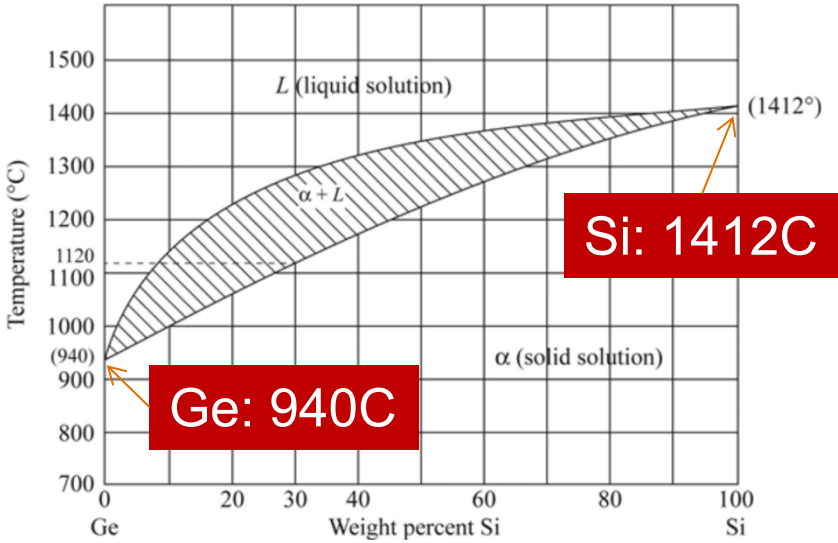
NEW CHANNEL MATERIALS DRIVING LOWER THERMAL BUDGET

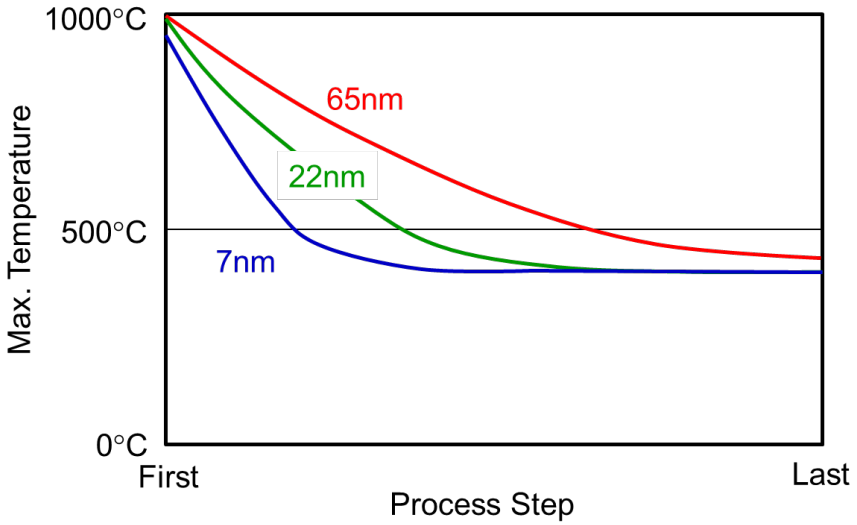
Thermal budget is squeezed in the middle

- Ge melting point is 940C versus 1412C for Si; many more process steps
- Need for low temperature high quality materials

Example: SiN for gate spacer

- Batch LPCVD: DCS + NH3 @ 650~750C
- Batch ALD: DCS + NH3 @ 500~650C
- Single wafer PEALD: novel precursors @ 350 to 550C





NEEDS FROM CHEMICAL SUPPLIERS

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HOW CHEMICAL SUPPLIERS CAN HELP

Novel materials

- Precursors for low-resistivity metals, ternary films with incorporation from the precursor as part of deposition process
- Highly reactive precursors that can enable fast film closure

Precursors with high reactivity at low temperature

- New materials are driving FEOL processes toward 400C
- Enabling low-T processes for existing materials like SiO and SiN

Chemicals that do not easily decompose even with long residence times in reactors for high-aspect ratio structures

- Solid precursors, lower-volatility liquids

Enable faster development cycle by doing more in-house pre-screening

- Representative reactors and structures to show upfront feasibility for step coverage, utilization, efficiency of incorporation

CONCLUSION AND SUMMARY

- **Moore's Law is increasingly a materials play**
  - Enabling materials such as HfO2, ZrO2, Si:Ge, Si:P, Co, …
  - Enabling processes for existing materials like LT SiO and SiN
- **New device architectures and EUV will drive stronger need for flexible chemistries and film properties**
- **Selective deposition in various combinations of surface and film type will be required**
- **Many opportunities for enabling materials solutions with innovative chemistries**

ACKNOWLEDGEMENTS

Thanks for your attention!

- Thanks to Ivo Raaijmakers, Bob Hollands, Bert Jongbloed, Jan Willem Maes, John Cossins, Hessel Sprey, and many others for providing material, and their help in preparing, for this presentation