AI-Native Equipment Design for Atomic Precision Etching

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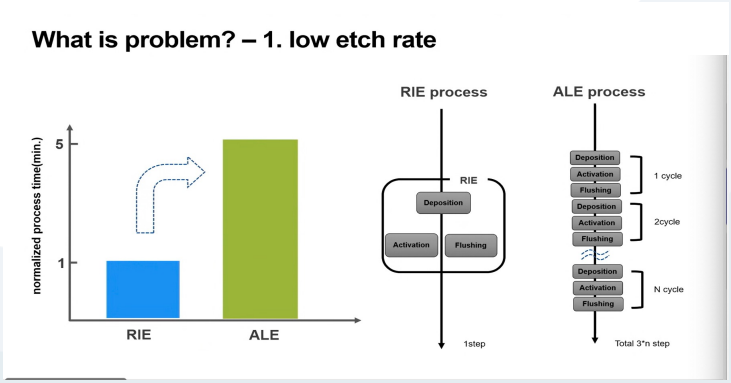
AAT located at Singapore One-North Tech Park

Outline

- Motivation: Angstrom Era Challenges
- AI-Native ALE System Design
- Process Engineering Domain Specific Language (PEDSL)
- Experimental Results: BKM1 & BKM2
- Comparison with State-of-the-Art
- Conclusions

The Angstrom Era Challenge

1. Sub-3nm nodes require atomic-scale precision etching
2. Traditional RIE causes damage & variability issues
3. Conventional ALE: coupled cycles → "pseudo-ALE" behavior
4. Low throughput and particle generation



Bai et al., Samsung Electronics, ALE Workshop 2024

Paradigm Shift: RIE → ALE; Recipe-Based → Adaptive Algorithmic Control

About AAT — Company Mission & Founder Team

Applied Angstrom Technology (AAT) — Singapore

Deep-tech equipment startup building the world's first AI-native atomic layer etching platform for advanced semiconductor manufacturing.

Our Mission

🎯 Enable true atomic-precision etching for sub-3nm nodes and 3D devices

🤖 Integrate AI natively into equipment — not bolt-on software

⚡ Deliver 10× faster ALE cycle time for HVM readiness

🔬 Democratize angstrom-scale process control via PEDSL

Founder Team — 20+ Years Combined Industry Experience

⚙️ Equipment Design (10 yrs)

Applied Materials & Lam Research

- ALE & etch chamber design and process development
- Plasma source engineering & gas delivery systems
- Led cross-functional next-gen platform teams

🏭 Fab Process Module (10 yrs)

Intel Corporation & TSMC & GlobalFoundries

- Directed etch integration for advanced nodes in both memory and logic
- Managed process roadmap and tool selection for technology development (TD) nodes
- Equipment-process co-optimization for HVM

SiN ALE: Process Significance, Prior Art & AAT Approach

Why SiN ALE Matters

- 3D NAND: tier nitride recess in 300+ layer stacks
- GAA Nanosheet: Inner spacer selective recess of SiN
- DRAM: Capacitor isolation & landing pad etch
- Patterning: SiN hardmask trim for sub-3nm CD control

Shared Chemistry: H_2 Modification + Fluorine Removal

Step 1: H_2 plasma → H radicals modify Si–N bonds (surface hydrogenation)

Step 2: NF_3/fluorine plasma → F radicals selectively remove modified layer

Product: Volatile $(NH_4)_2SiF_6$ (AFS) → desorbs as $SiF_4 + NH_3 + N_2$

Prior Art & AAT: Same Chemistry, Different Architecture

Sherpa et al. (TEL) — JVSTA 2017		Rui et al. (Micron) — JVSTA 2023		AAT (This Work) — SPIE 2026	
Platform:	CCP (coupled RF)	Platform:	ICP (conventional)	Platform:	Decoupled AI-Native
Chemistry:	H_2 mod. + NF_3 removal	Chemistry:	H_2 mod. + NF_3 removal	Chemistry:	H_2 mod. + NF_3 removal
EPC:	~61 Å/cycle	EPC:	~90 Å/cycle	EPC:	**2.3–90 Å/cycle (tunable)**
Synergy:	>80%	Synergy:	>80%	Synergy:	>80–90%
Cycle Time:	~30 s	Cycle Time:	5–30 s	Cycle Time:	**~2 s (10× faster)**
Limitation:	Coupled source → limited step-level optimization	Limitation:	Sequential pulsing in single chamber	Advantage:	Independent step control via PEDSL + AI optimizer

AI-Native ALE: Process Steps & System Architecture

Figure 1a. ALE Process Steps

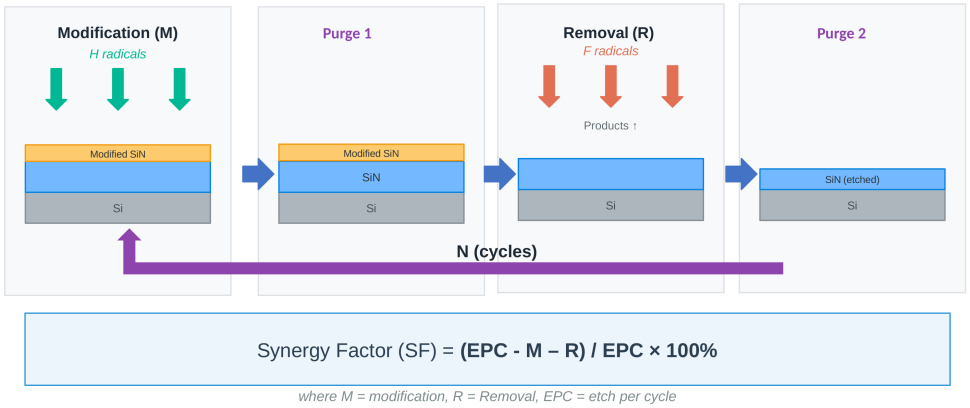
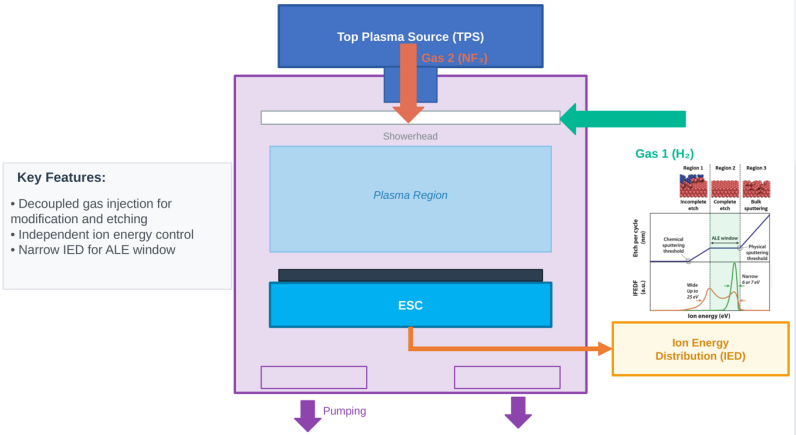
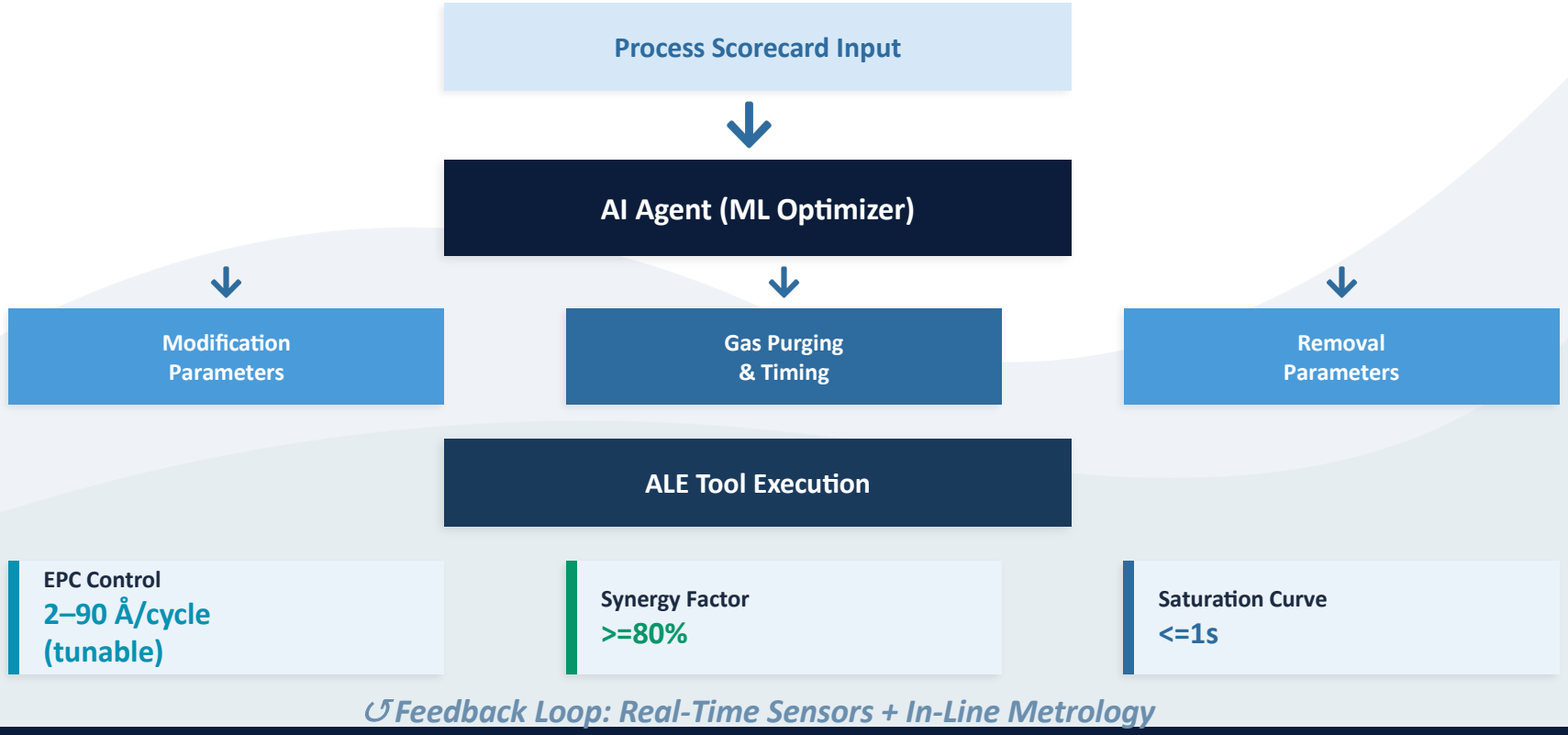


Figure 1b. Decoupled ALE System Architecture



Process Engineering DSL (PEDSL)



Two Process Conditions (Best Known Methods)

BKM1: High Throughput

- EPC: ~90 Å/cycle
- Synergy: >90%
- $R^2 > 0.99$ linearity
- Cycle time (mod. + rem.): ~2 s
- Use: Bulk removal

BKM2: Atomic Precision

- EPC: ~2.3 Å/cycle
- Synergy: >80%
- $R^2 > 0.99$ linearity
- Cycle time (mod. + rem.): ~2 s
- Use: Surface smoothing

Key Advantage: 10× faster cycle time (~2 s vs. ~30 s) — Algorithmic selection of optimal process window

Etch Linearity Results

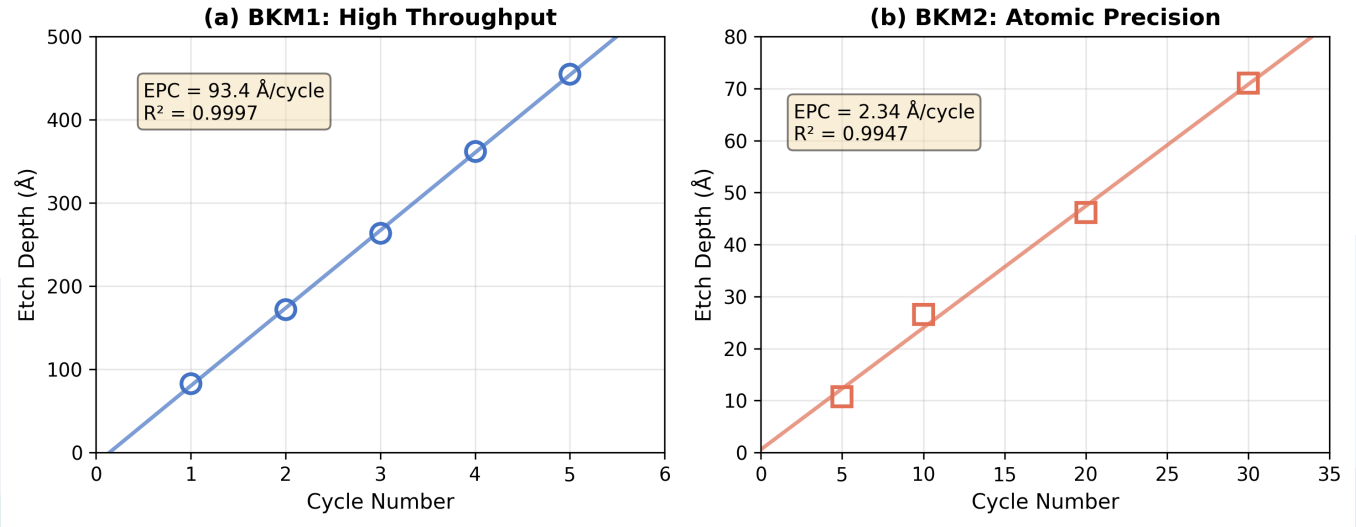


Figure 2: BKM1 (~90 Å/cycle) and BKM2 (~2.3 Å/cycle) both demonstrate $R^2 > 0.99$ linearity

BKM1: EPC = 93.4 Å/cycle

BKM2: EPC = 2.34 Å/cycle

Modification & Removal Saturation

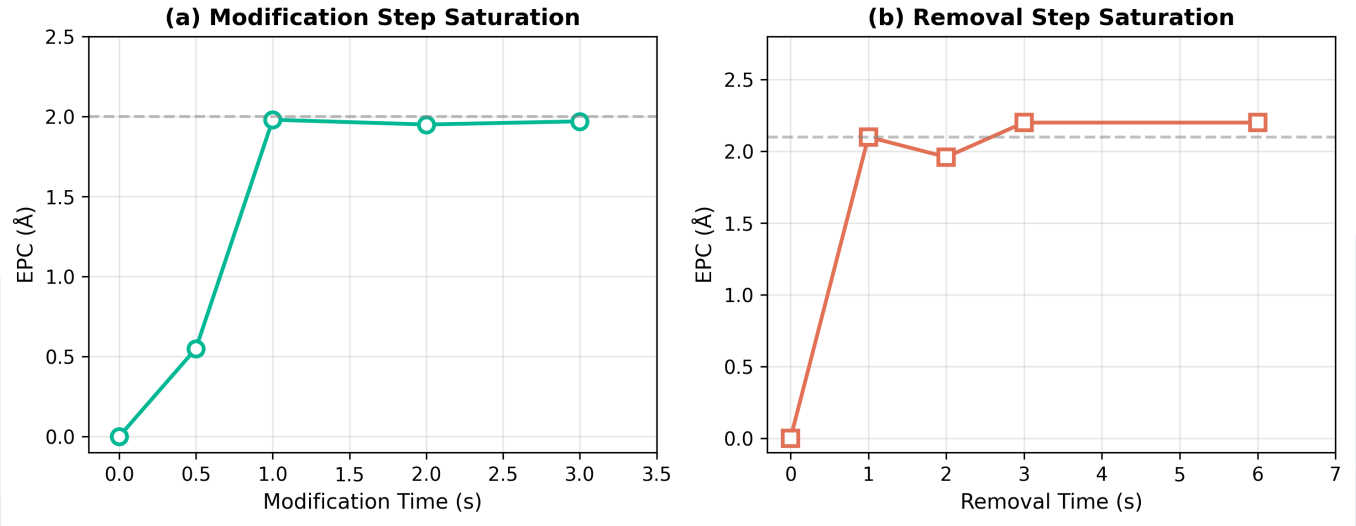


Figure 3: Modification saturates at ~2.0 Å (1s); Removal saturates at ~2.1 Å (1s) → Self-limiting confirmed

Modification: saturates ~2.0 Å @ 1s

Removal: saturates ~2.1 Å @ 1s

Synergy Factor Analysis

$$SF = (EPC - M - R) / EPC \times 100\%$$

where M = modification-only etch, R = removal-only etch

BKM1 Synergy
>90%

BKM2 Synergy
>80%

Removal sat.
~2.1 Å @ 1s

Modification sat.
~2.0 Å @ 1s

Results

- >80% synergy confirms ALE behavior
- Minimal physical sputtering contribution
- Both steps show self-limiting saturation
- Independent optimization enabled by PEDSL

Comparison with State-of-the-Art

Process	EPC	Synergy	Cycle Time	Ref
BKM1 (This work)	**90 Å**	**>90%**	**~2s**	**This work**
BKM2 (This work)	**2.3 Å**	**>80%**	**~2s**	**This work**
CCP H_2/NF_3	61 Å	>80%	~30s	Sherpa, JVSTA 2017
ICP H_2/NF_3	~90 Å	>80%	5–30s	Rui, JVSTA 2023
Thermal TMA/HF	1.06 Å	~40%	~90s	Junige, Chem. Mater. 2024
FC Plasma C_4F_8	5–8 Å	~75%	20–60s	Li, JVSTA 2016

Key Differentiator: 10× faster cycle time vs. conventional ICP ALE (~2 s vs. ~30 s) with comparable synergy — PEDSL enables independent step optimization

Conclusions

- AI-native ALE achieves true self-limiting behavior (>80% synergy)
- Decoupled modification/removal enables rapid process iteration
- BKM1: High throughput (~90 Å/cycle) for bulk removal
- BKM2: Atomic precision (~2.3 Å/cycle) for surface smoothing
- 10× faster cycle time (~2 s vs. ~30 s conventional ICP ALE)

Viable pathway for sub-3nm nodes & complex 3D architectures

Join Us in Singapore's Deep-Tech Ecosystem

one-north — Singapore's Innovation District

- 200-hectare R&D hub: Fusionopolis, Biopolis, Mediapolis
- Home to A*STAR research institutes & global tech labs
- Deep-tech startup ecosystem with world-class cleanrooms
- Strategic gateway connecting Asia-Pacific semiconductor markets

We're Hiring — Open Roles

- **Plasma / Etch Process Engineer**
  ALE process dev, chamber tuning, recipe optimization
- **AI / ML Engineer**
  Real-time process control, PEDSL, sensor fusion
- **Hardware Design Engineer**
  Plasma source engineering, gas delivery

Global Hub	Talent Pool	Backed By	Infrastructure
Asia-Pacific semiconductor market gateway	NTU, NUS, SUTD, SIT A*STAR institutes	iGlobe Partners, EDBi Enterprise Singapore	one-north R&D hub World-class cleanrooms

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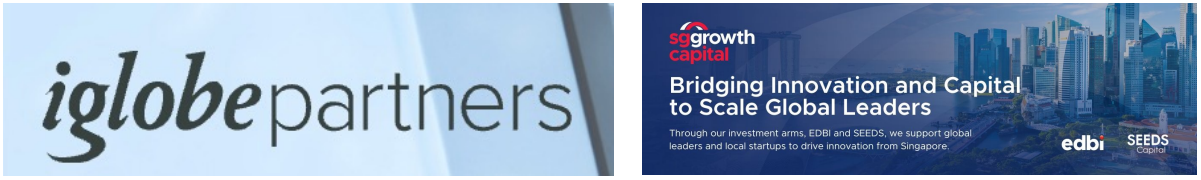

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Thank You

Questions?

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