ALD W and TiN for Advanced Contact Application

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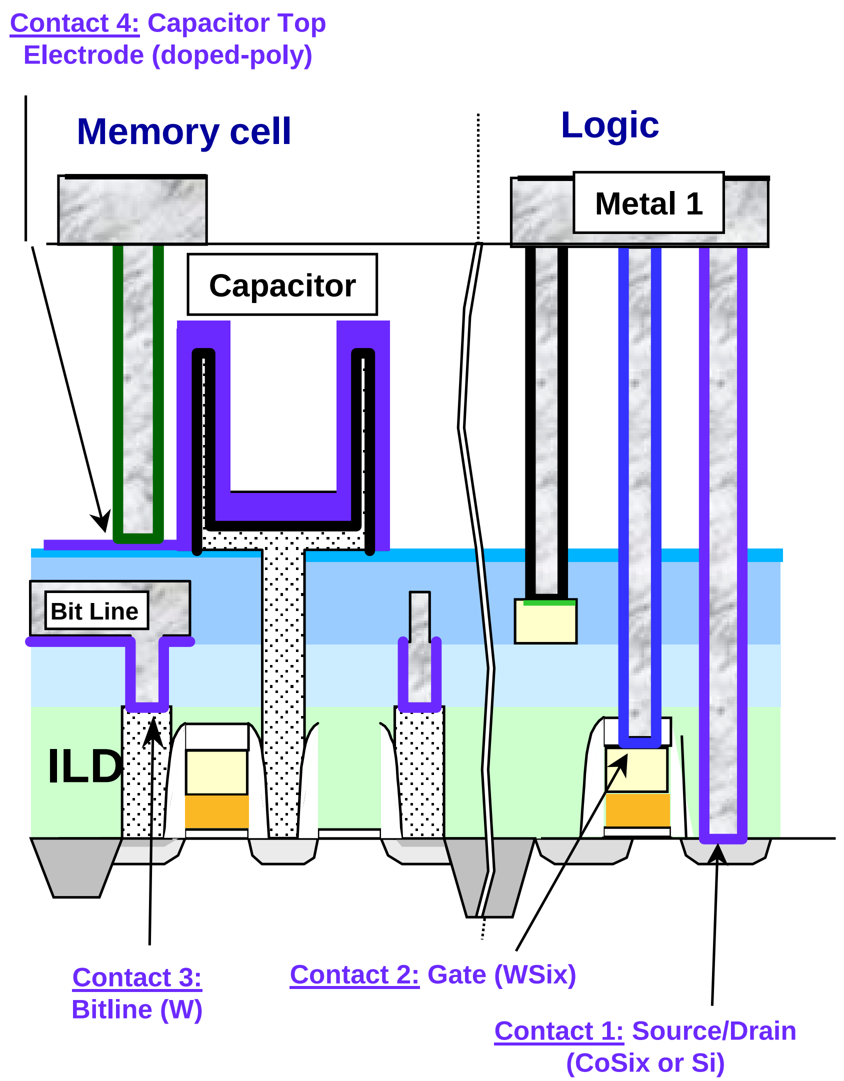
Contact Meta Deposition Devision

Applied Materials

Metallization requirements in DRAM / EDRAM

- *Device Requirements*
  - *Minimal CD change*
  - *Low Contact Resistance and junction leakage*
  - *High capacitance with low leakage*

- *Process/Hardware Requirements*
  - *Aspect ratio independent contact pre-clean*
  - *HAR contact liner/barrier*
  - *Seamless W plug fill*

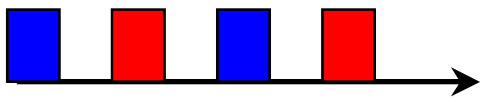


Complete contact process

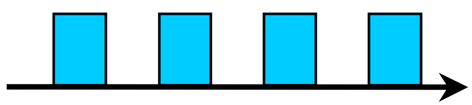
Atomic Layer Deposition -
New Deposition Technique for 100 nm device and Beyond

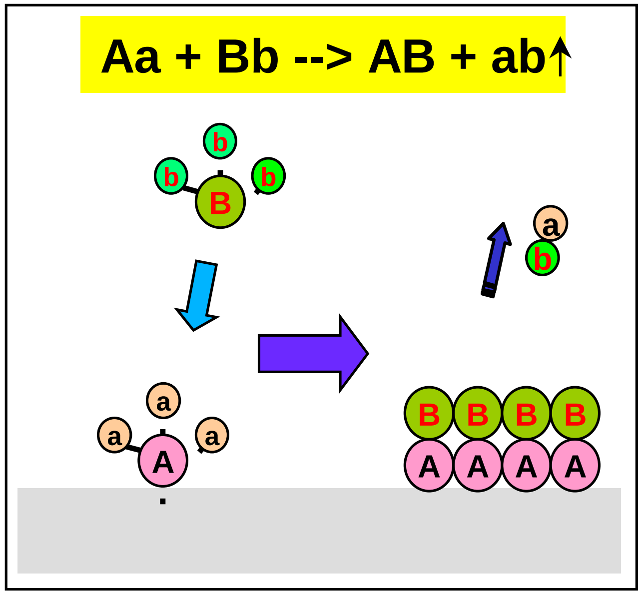
Concept Description

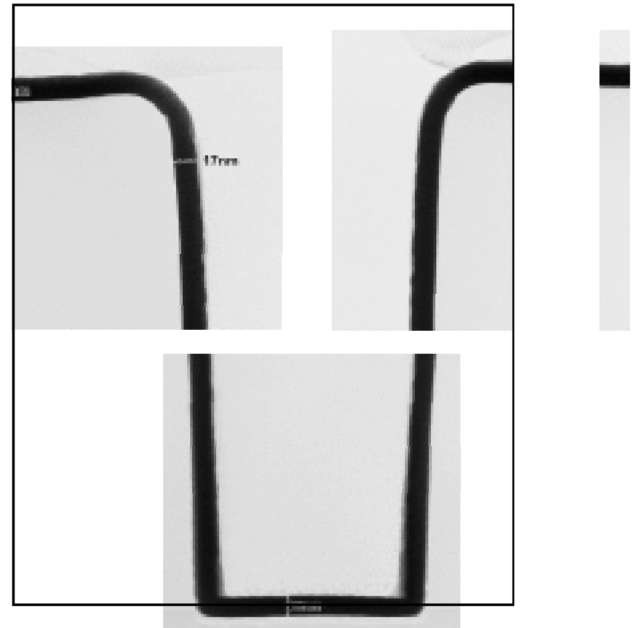
Reactant Exposure



Purge Gas



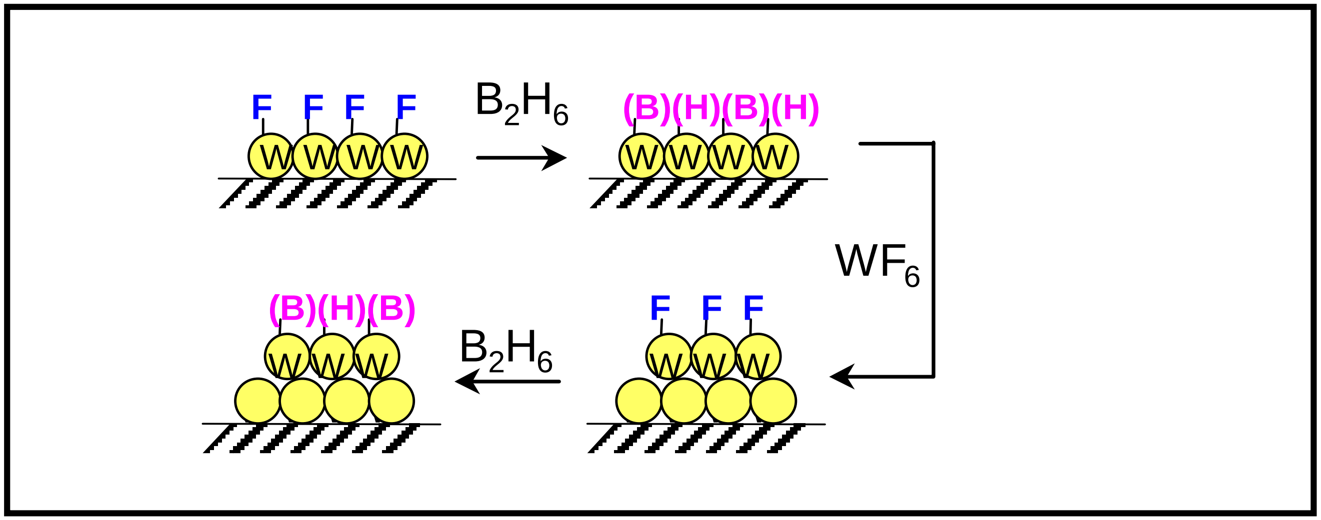




- Alternative introduction of two reactants
- Film growth is mono-layer by mono-layer
- Capable of depositing high quality thin films with accurate thickness control: low defect density, excellent conformity and step coverage

WF_6/B_2H_6 ALD Chemistry

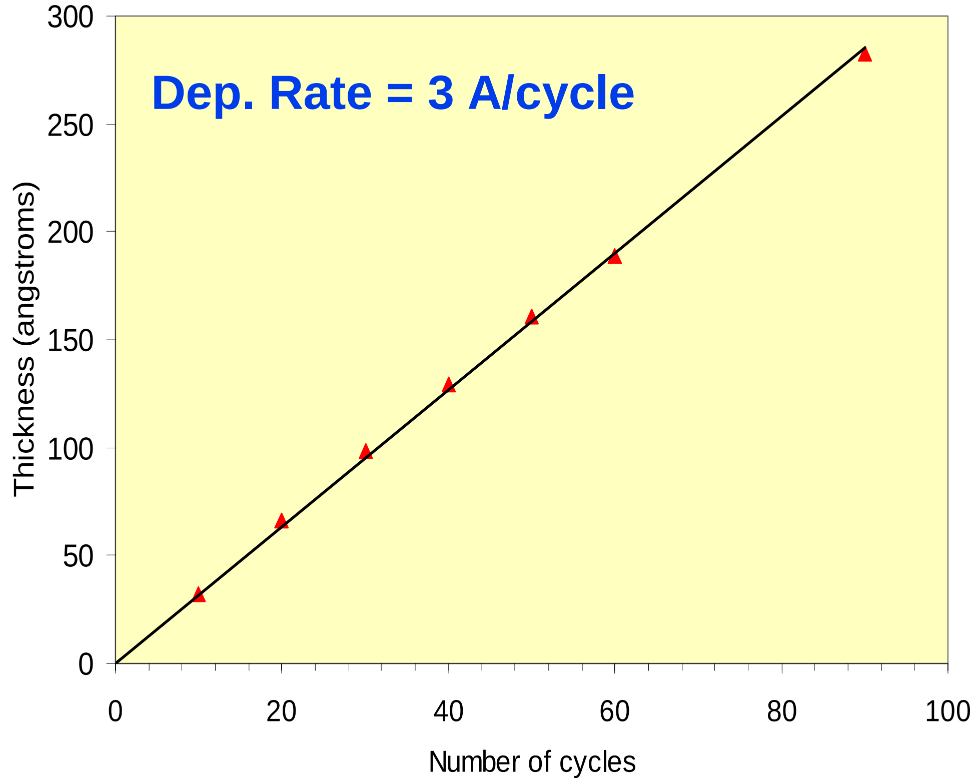
$$WF_6 + B_2H_6 \longrightarrow W + HF + BF_3$$



- B_2H_6 is a more reactive reducing agent compared with SiH_4
- WF_6/B_2H_6 reaction completes < 300 C and leaves little F residue

WF_6/B_2H_6 Tungsten ALD Process

Process Linearity

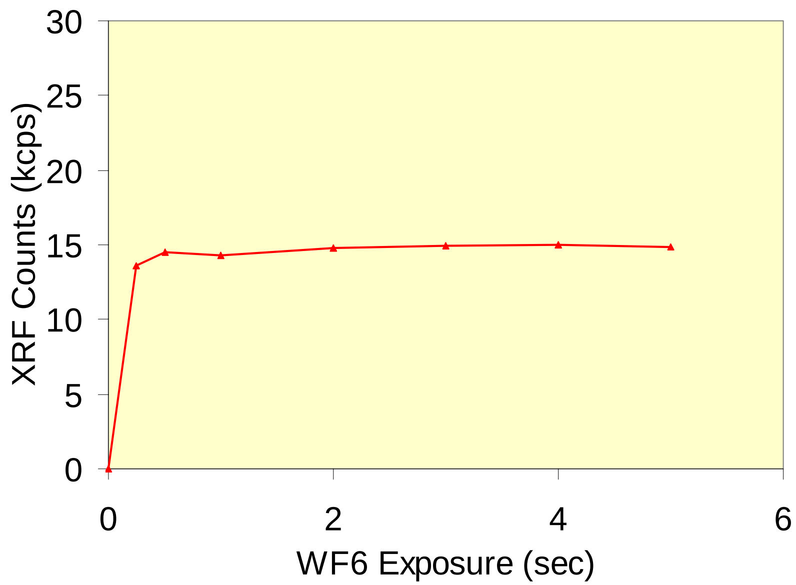


Film thickness is linear with number of cycles. Linearity maintained at >30 wph throughput for 50-100 A film. Resistivity stable across thickness range.

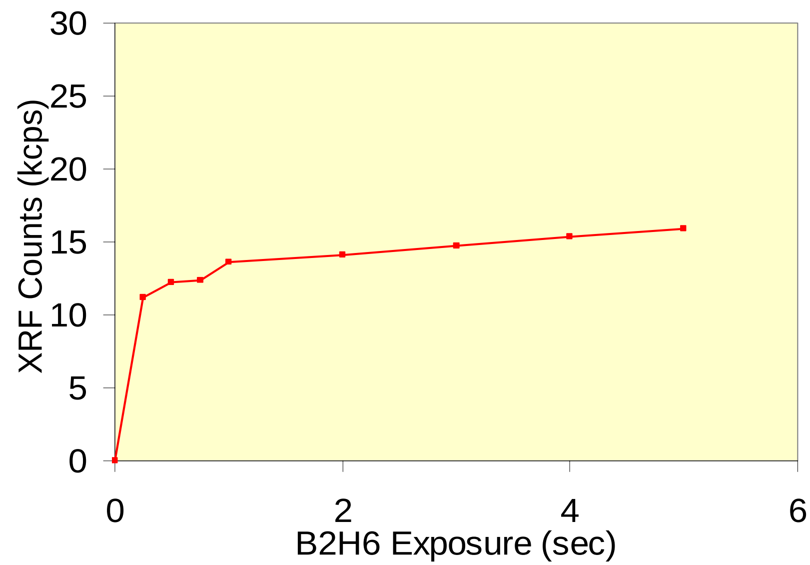
WF_6/B_2H_6 Tungsten ALD Process

Gas Flow Requirements

WF_6 exposure dependence



B_2H_6 exposure dependence

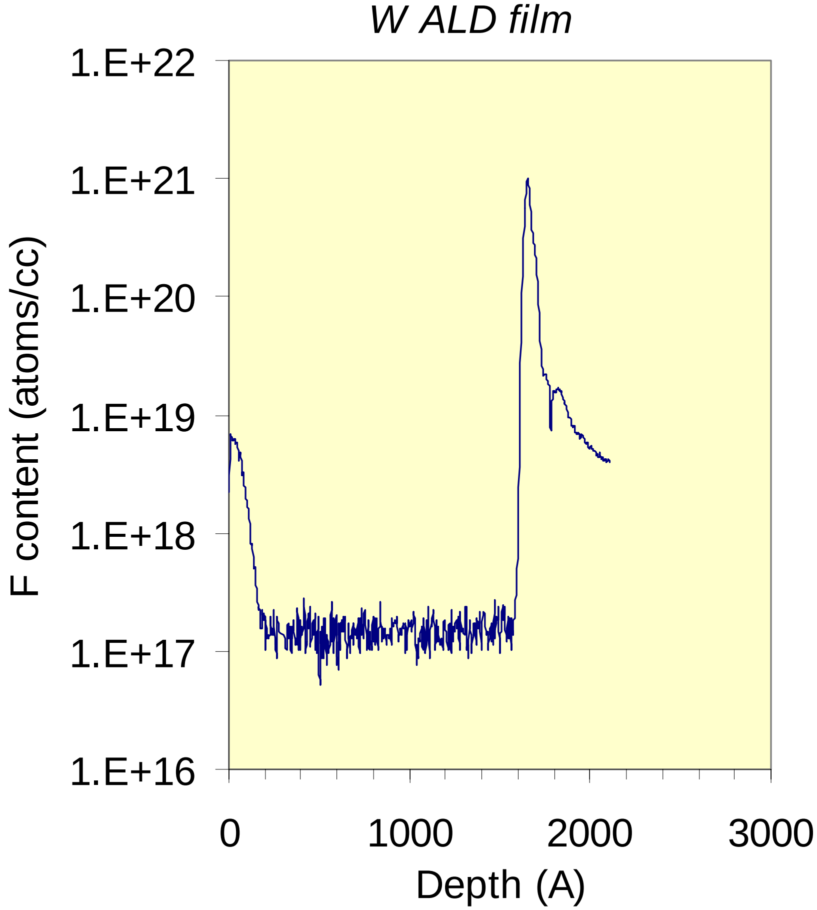


Growth is self limiting with WF_6 and B_2H_6 exposure

The critical factor - rapid, sequential introduction and purging of reactants.

WF_6/B_2H_6 Tungsten ALD Process

Fluorine Concentration in W Film, SIMS data

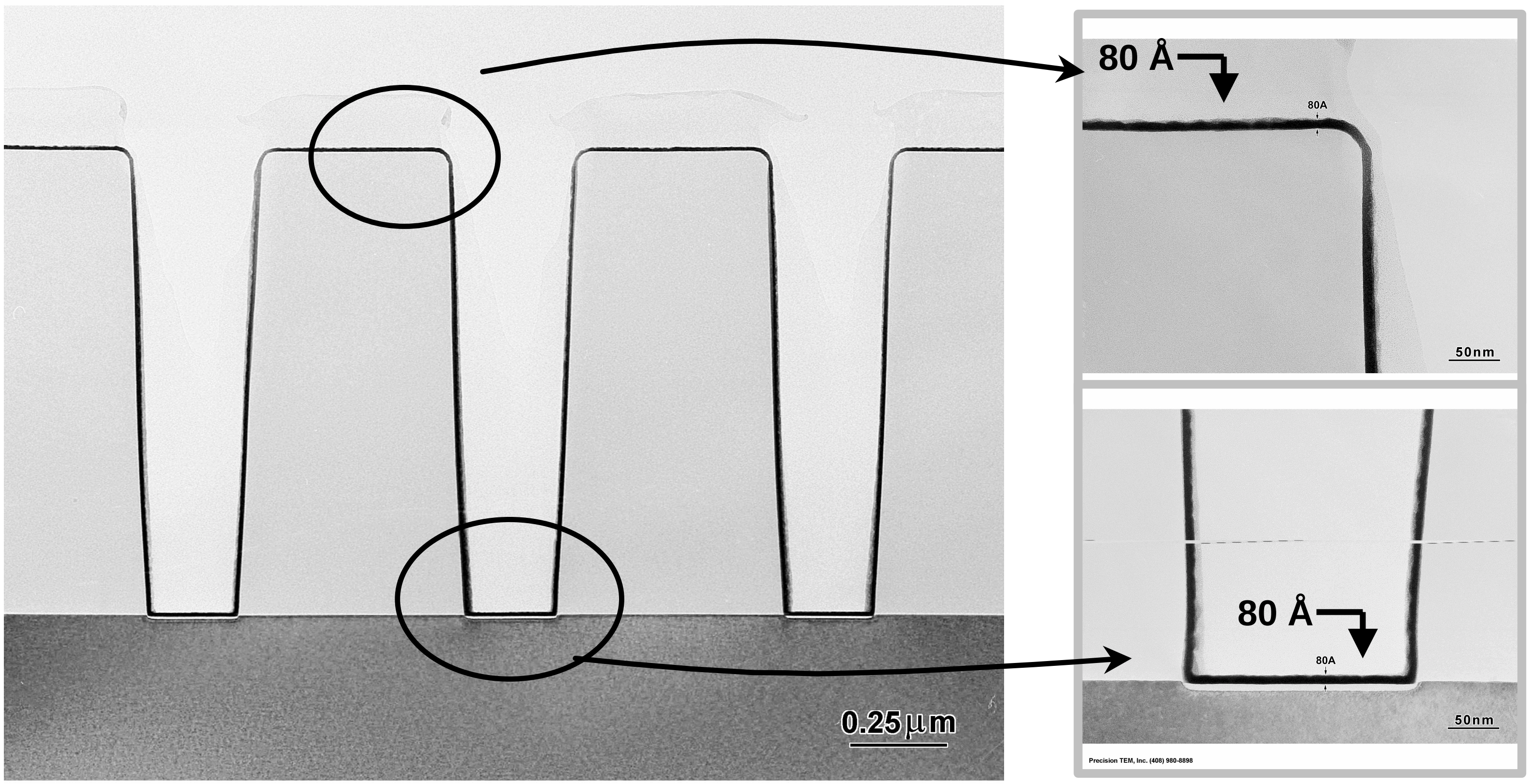


- **F concentration less than 5E17 atom/cm^3 in W ALD film**
- **Reduced interface F concentration for integrated film stack**

WF_6/B_2H_6 Tungsten ALD Process

TEM of Atomic Layer Nucleation Film (8 nm)

Step coverage 100%



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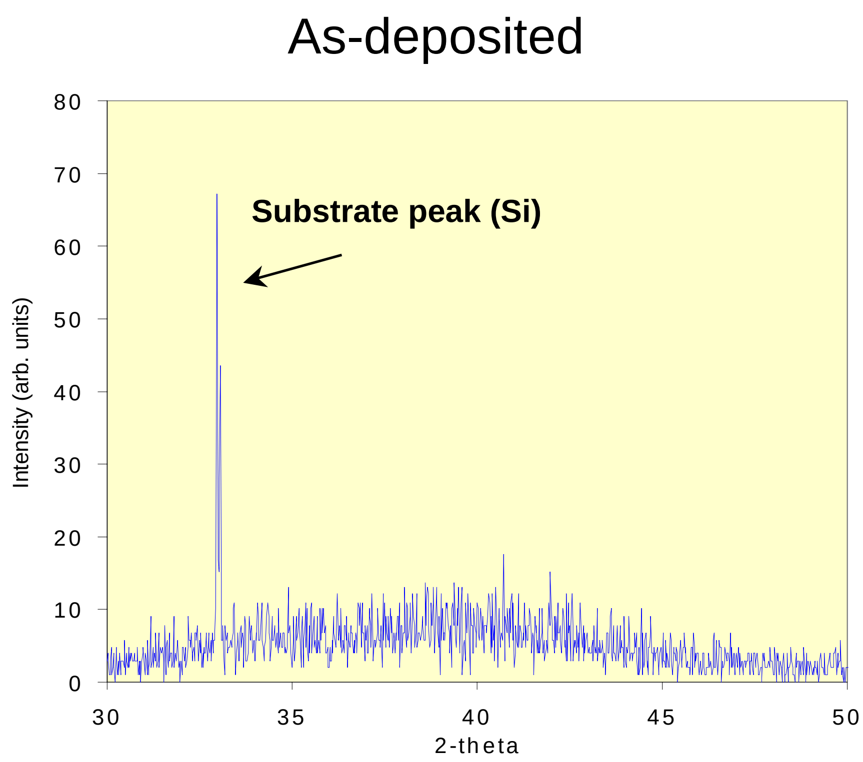
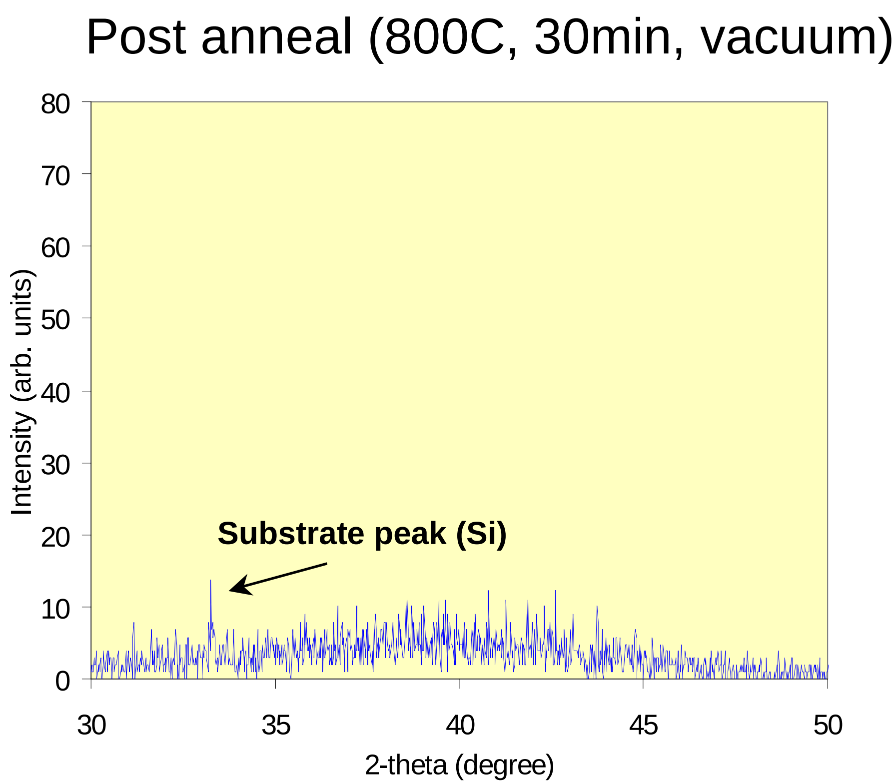
WF_6/B_2H_6 Tungsten ALD Process

Film Structure, XRD Data

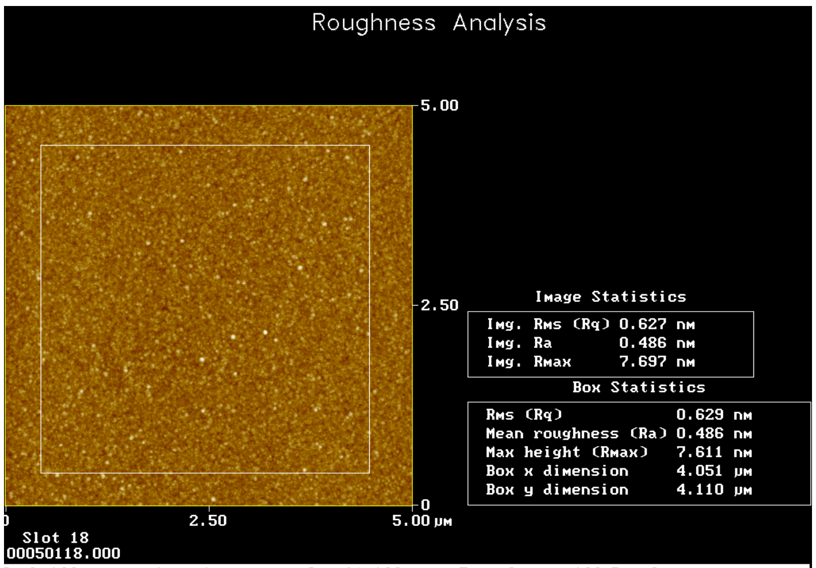


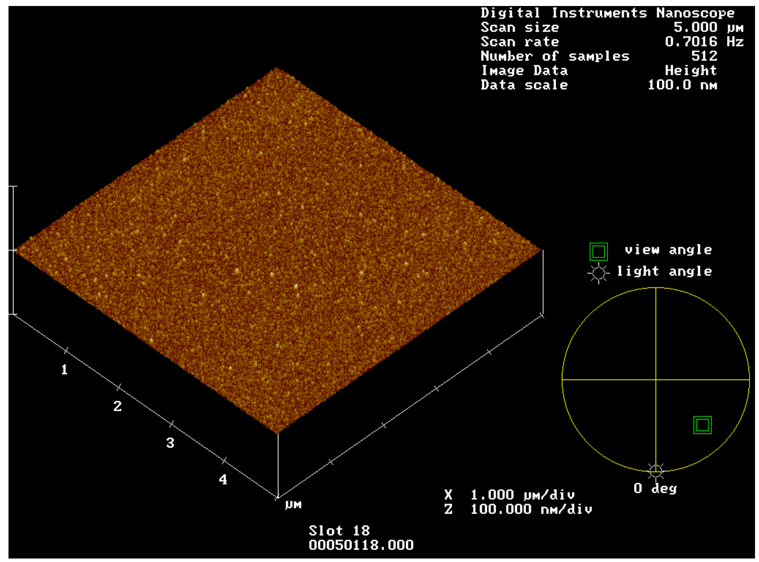


WF_6/B_2H_6 ALD Tungsten maintains an amorphous structure after 800 C anneal

WF_6/B_2H_6 Tungsten ALD Process

Film Roughness of W ALD Film: AFM data

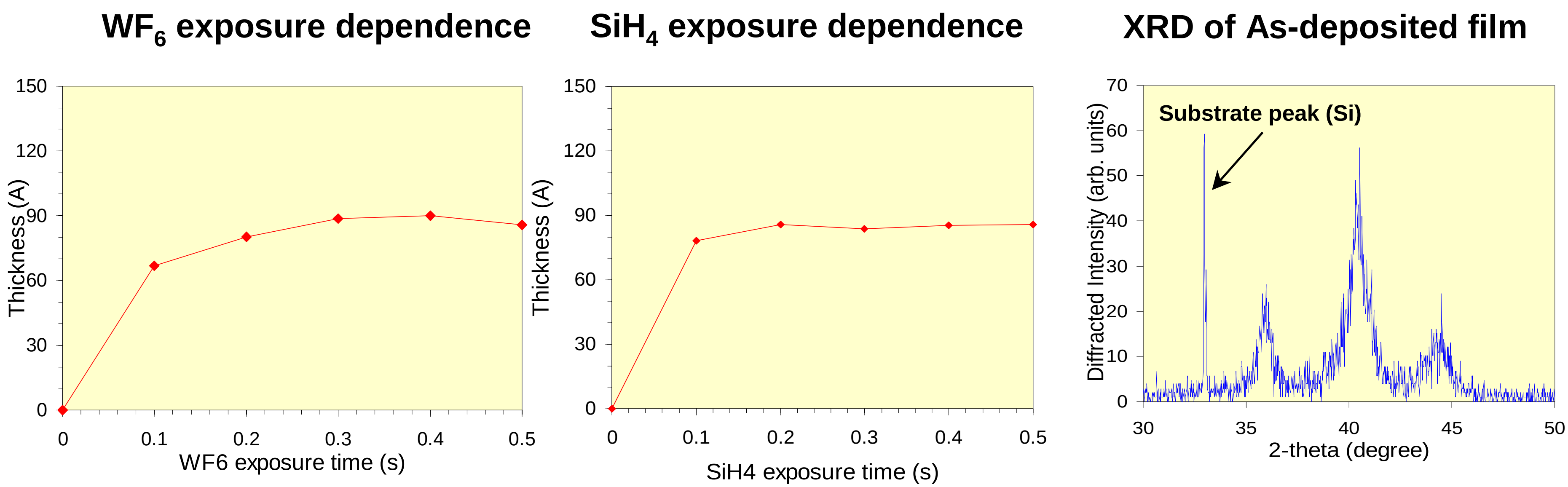




Extremely smooth surface of ALD film: 6 A RMS for 1000 A film

WF_6/SiH_4 Tungsten ALD Process

Process Characterization

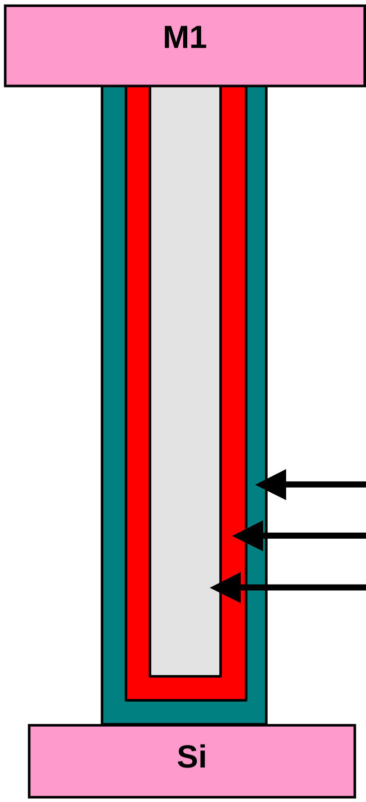


- Growth is self-limiting with WF_6 and SiH_4 exposure.
- WF_6/SiH_4 ALD produces crystalline film.

ALD deposition behavior demonstrated for WF_6/SiH_4 chemistry.

Tungsten CVD - Applications and Trends

Continuously Shrinking Contact Size



Conventional tungsten nucleation and liner / barrier layers fill an entire 0.11-µm diameter contact

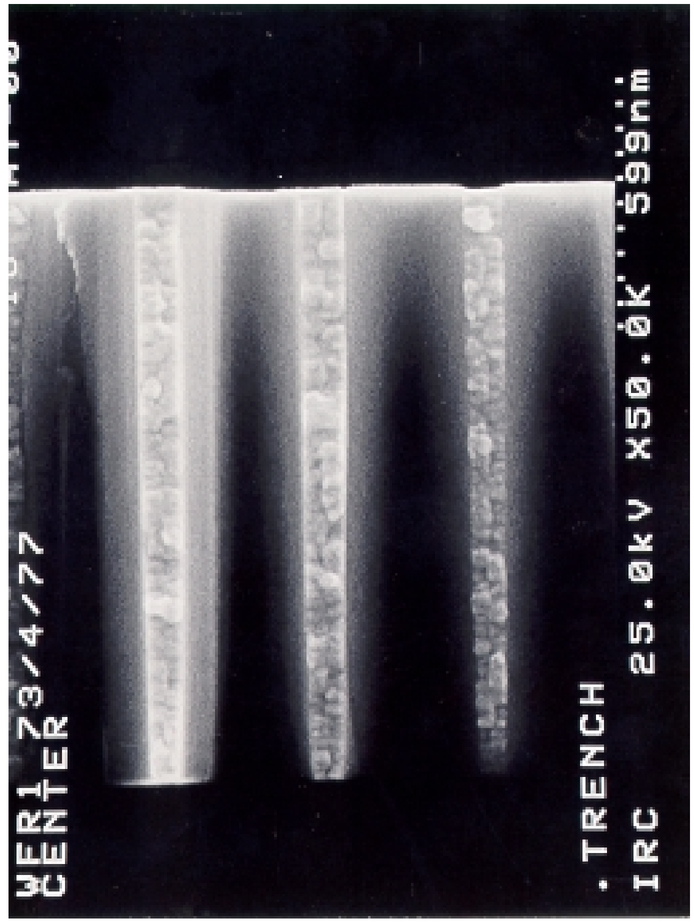
Approximate Resistivity / Thickness Values

Ti/MOCVD TiN	200 µΩ-cm / 150 Å
Tungsten nucleation	20 µΩ-cm / 400 Å
Bulk tungsten	10 µΩ-cm

As contact diameter shrinks, the low-resistivity bulk tungsten metal component of the contact plug shrinks, driving up plug resistance.

W ALD Nucleation Layer

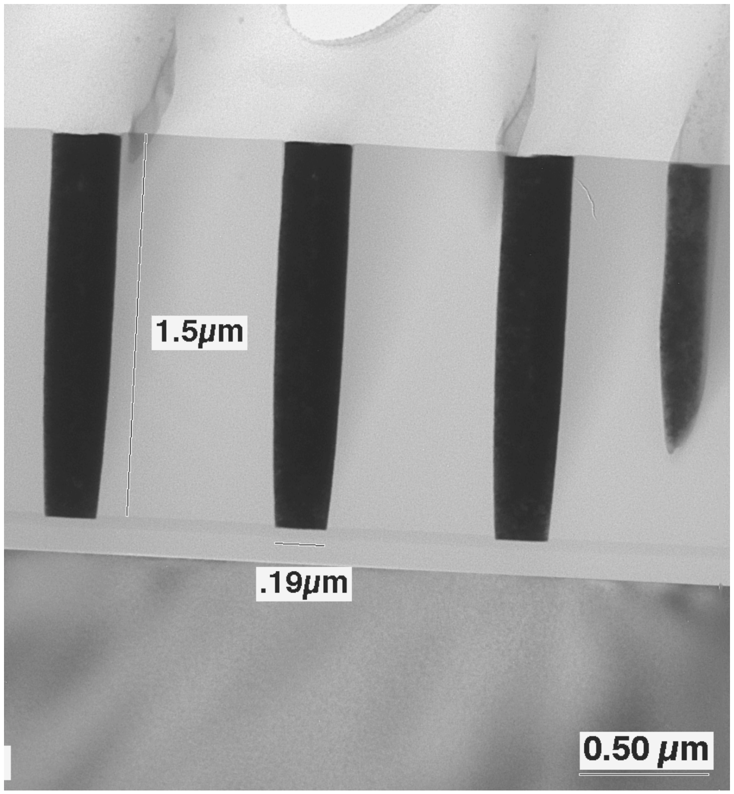
50 A ALD W nucleation
300 torr bulk deposition
1.5 x 0.07u trench structure



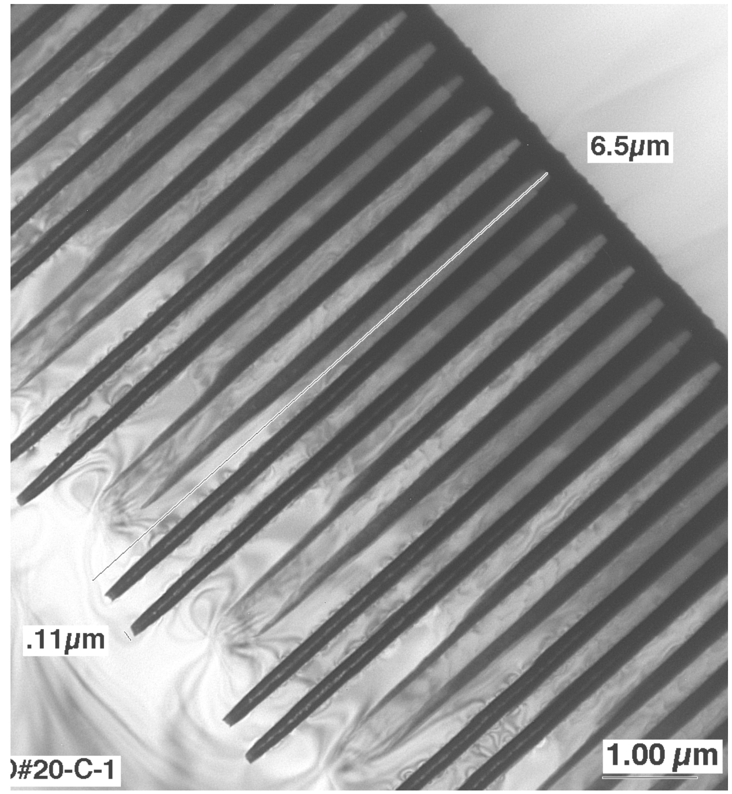
- **Seamless W plug fill using ALD nucleation layer**

WF_6/B_2H_6 Tungsten ALD Process

ALD Nucleation



Contacts: 0.20μm, AR=8:1, Post-CMP
25Å **ALD Nucleation Layer**

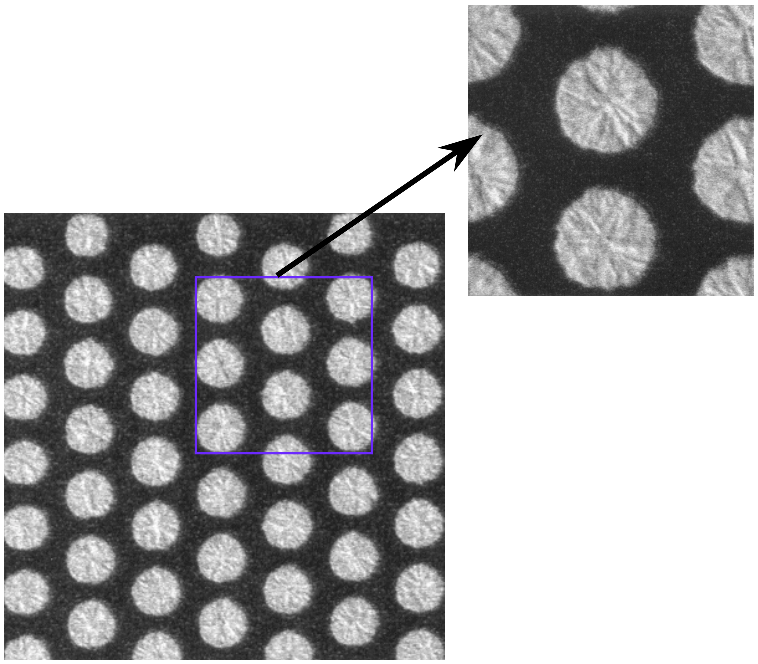


Trench: 0.18 μm, AR = 60:1
50 Å **ALD Nucleation Layer**

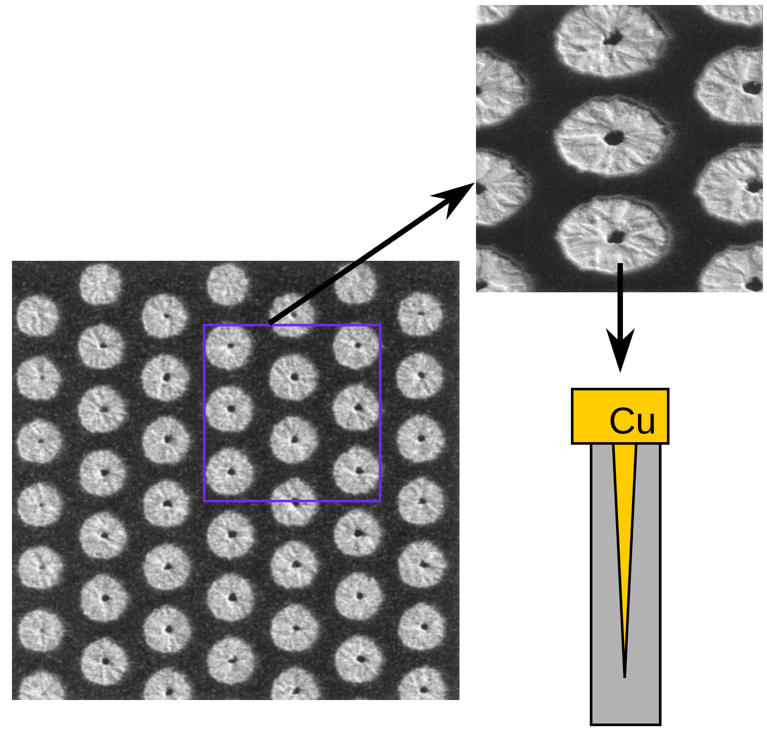
ALD Nucleation provides ultrathin nucleation layer with 100% step coverage.

Post CMP Data - Tungsten Fill with ALD Nucleation

Extendibility to 0.1u device



ALD nuc + 300T CVD bulk
Dimple density in array : <5%
Average dimple size: <50 A

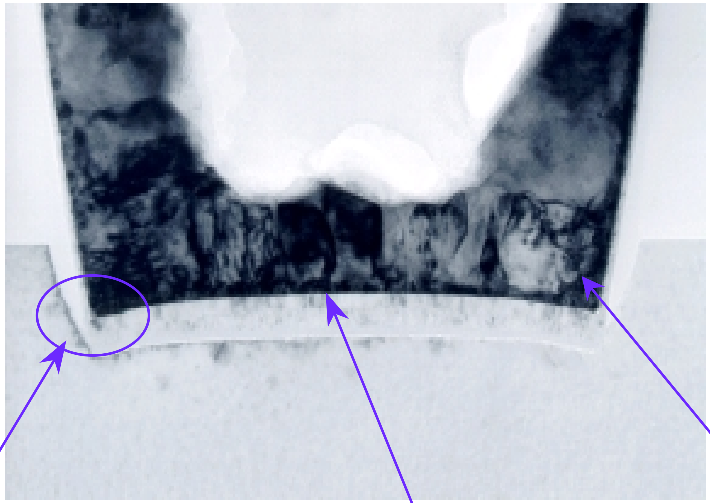


CVD nuc + 300T CVD bulk
Dimple density in array: >60%
Average dimple size: 400 to 550A

ALD nucleation + bulk fill tungsten provides virtually dimple free plugs after CMP - a critical requirement for integration with subsequent copper metallization

ALD W Nucleation

TEM images of Contact



No WF6 attack of Ti/TiN

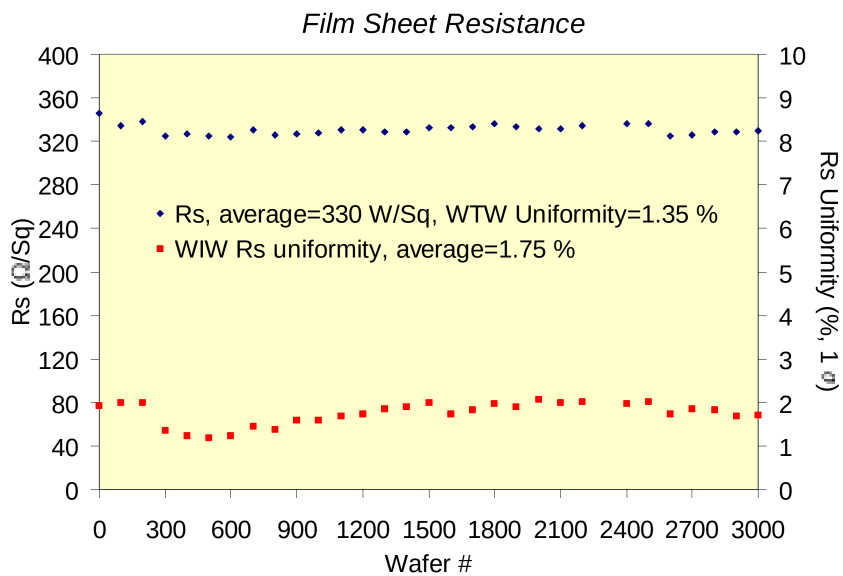
IMP Ti/MOTiN

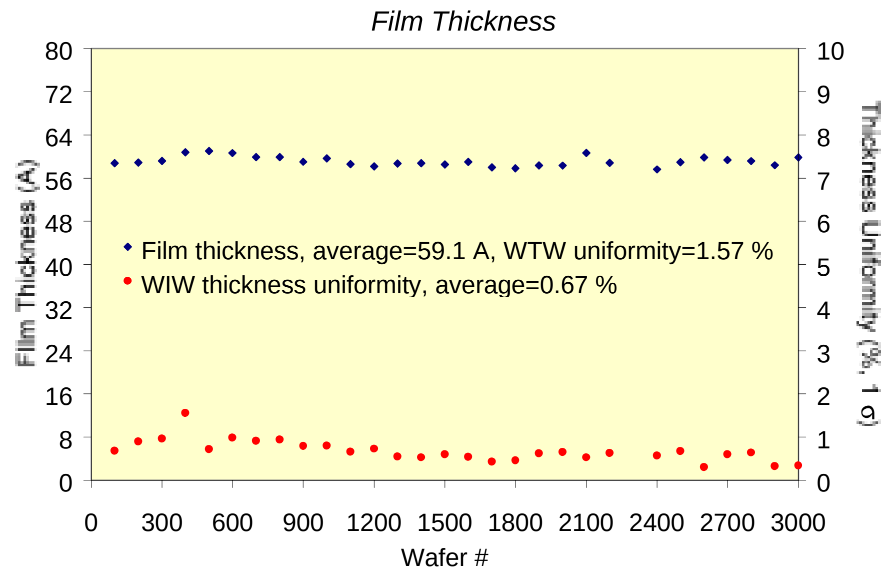
50 A of ALN layer

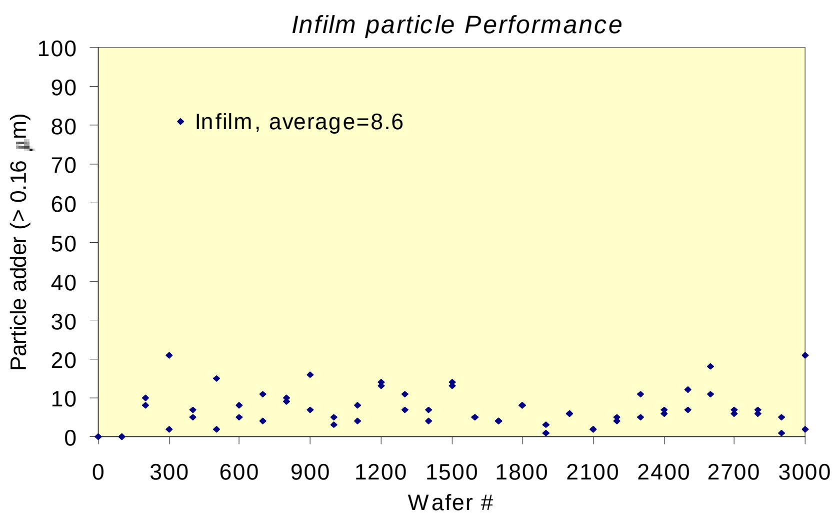
- **F attack can occur during WF6 exposure, especially for large dose and high pressure at high temperature**
- **Optimized process produces clean W/TiN/Ti interfaces. No signs of F attack or other abnormality was observed.**

WF$_6$/B$_2$H$_6$ Tungsten ALD Process

Process Repeatability







- **Stable process over both 200 mm and 300 mm**
- **Rs Wafer-to-wafer Uniformity <1.35%**
  Within-wafer Uniformity <1.75%
- **Particle performance (>0.16 µm):**
  Mechanical = 0.02 defects/cm^2
  In-film = 0.03 defects/cm^2
- **Production worthy thpt: 30 wfr/hr/chamber**

Stable performance proven over extended wafer runs.

APPLIED MATERIALS®

Summary

- ALD W process provides conformal nucleation layer with excellent step coverage. Enable W plug fill to 100nm device and beyond.

- Using B_2H_6/WF_6 chemistry, ALD nucleation layer thickness is reduced to < 100 A. Combined with 300 torr bulk deposition, W plug is seamless after CMP.

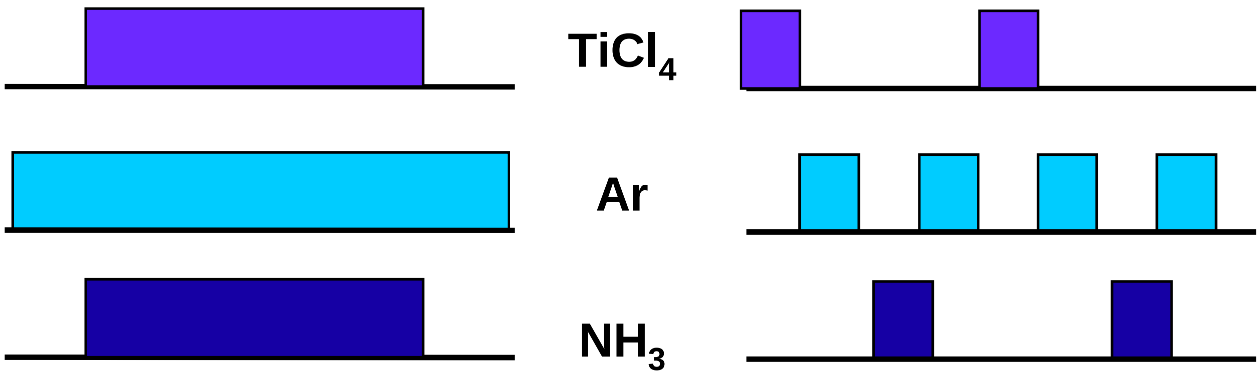
- High reactivity of B_2H_6 produces W film with low F content, reduces nucleation sensitivity to TiN substrate, thus enlarges process integration window.

- Robust and production-ready B_2H_6/WF_6 ALD process and hardware has been developed in both 200mm and 300mm.

ALD $TiCl_4$ TiN

Comparison of Deposition Methods

	CVD TiN	ALD TiN
Gas Flow into Chamber	$TiCl_4$ & NH_3 simultaneously	$TiCl_4$ & NH_3 separately



	CVD TiN	ALD TiN
Reaction Mode	Surface & Gas phase reaction	Surface reaction only
Film Growth	Continuous growth	Digital growth

With ALD, highly conformal, low impurity films can be obtained at low deposition temperatures, with excellent thickness control

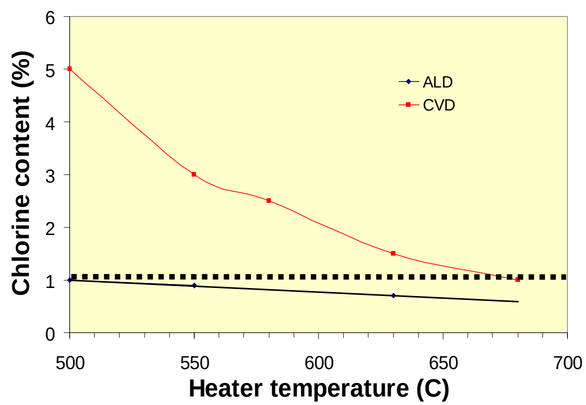
$TiCl_4$ ALD Titanium Nitride

Capacitor Electrode Application (MIS)

Key Requirements

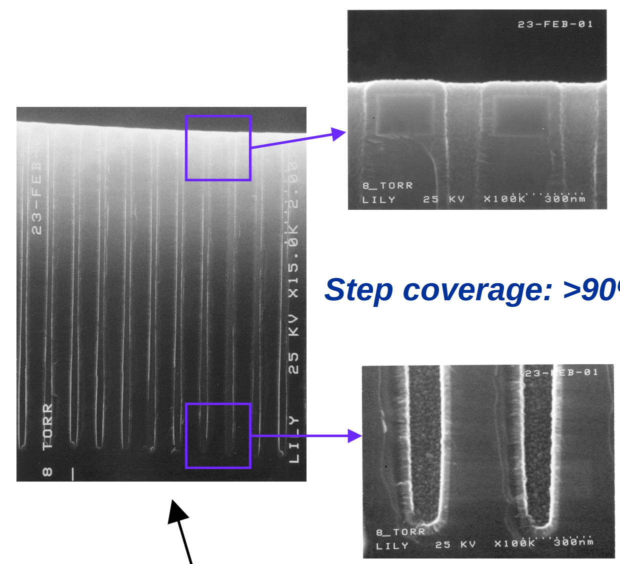
Parameter	Requirement	ALD TiN Performance
Temperature	<500^{o}C (wafer temp)	<480^{o}C
Chlorine content	<1%	<1%
Step Coverage	>90% on >30:1 AR	>90%
Leakage current	<1E-8 A/cm^2	<<1E-8 A/cm2

Chlorine Content



1 %

Step Coverage



Step coverage: >90%

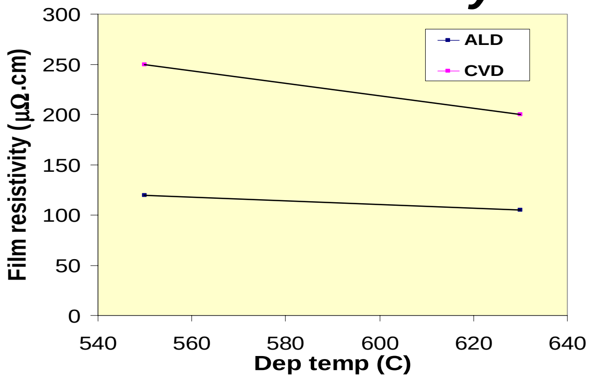
0.13- 0.23μm x 7.25μm (AR: 30-50)

ALD TiN can provide extremely conformal, excellent quality film for MIS capacitor electrode application (≤0.13μ devices)

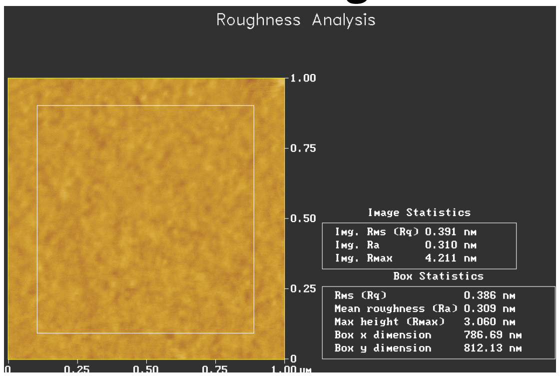
$TiCl_4$ ALD Titanium Nitride

Contact Application

Film Resistivity

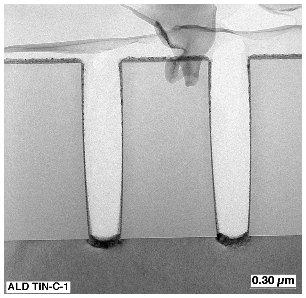


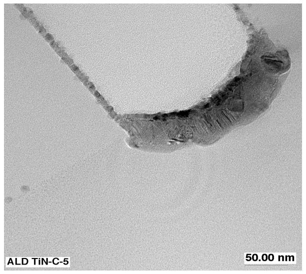
Surface Roughness

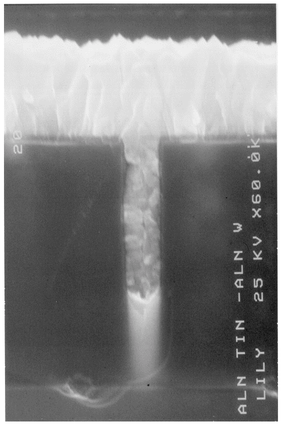


Roughness (rms): 3.9 A over 300 A film

Process Compatibility







RPC+ / CVD Ti (200A) / ALD TiN (50A)

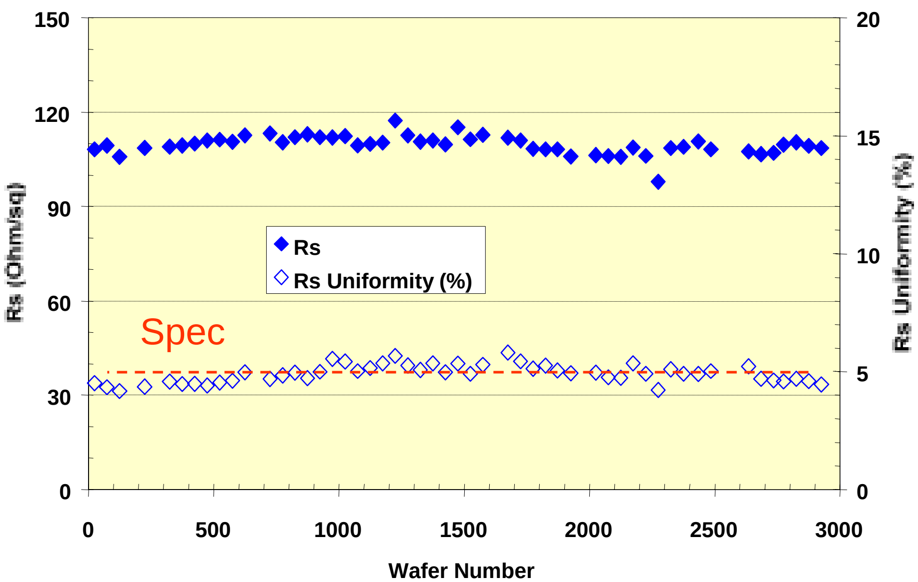
+ ALD W nuc. (50A) / CVD W bulk

ALD TiN can provide low temp, extremely conformal, low resistivity, excellent barrier film for contact application (≤0.1μ devices)

$TiCl_4$ ALD Titanium Nitride

3000 Wafer Marathon Data (500C process)

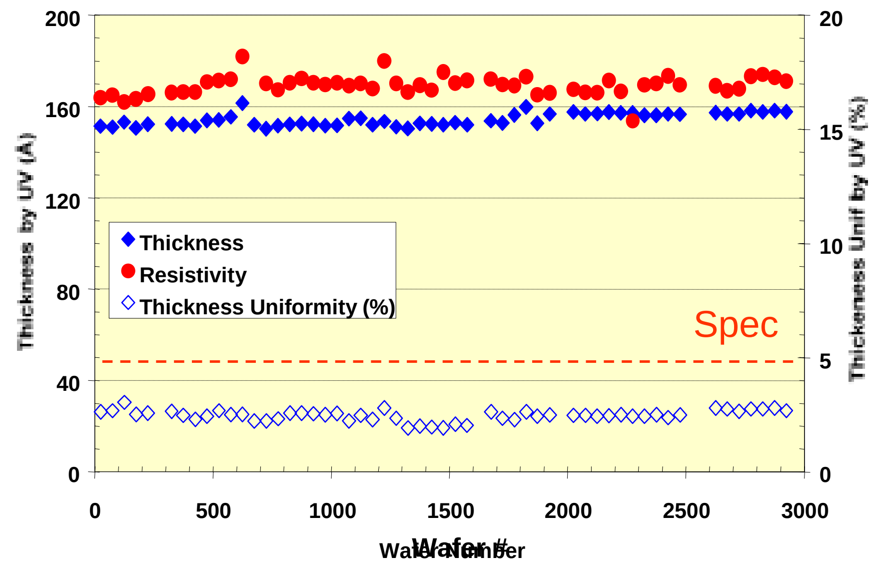
Rs & Rs uniformity



Wiw unif (3mm EE): 4.9%

wtw unif (3mm EE): 2.8%

Thickness & Thickness uniformity



Wiw unif (6mm EE): 2.5%

wtw unif (6mm EE): 1.5%

Stable, clean, 100% step coverage, low resistivity (<170uohm-cm) and low thermal budget process