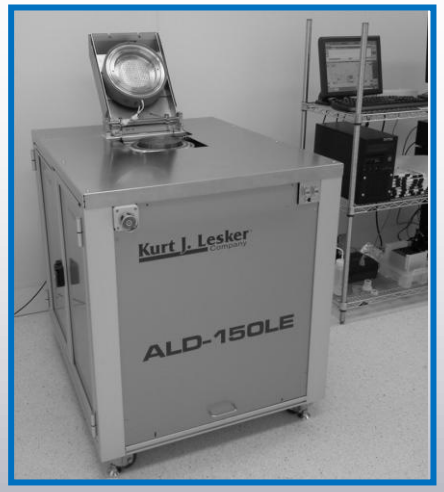
ALD Capabilities at Penn State

Bangzhi Liu

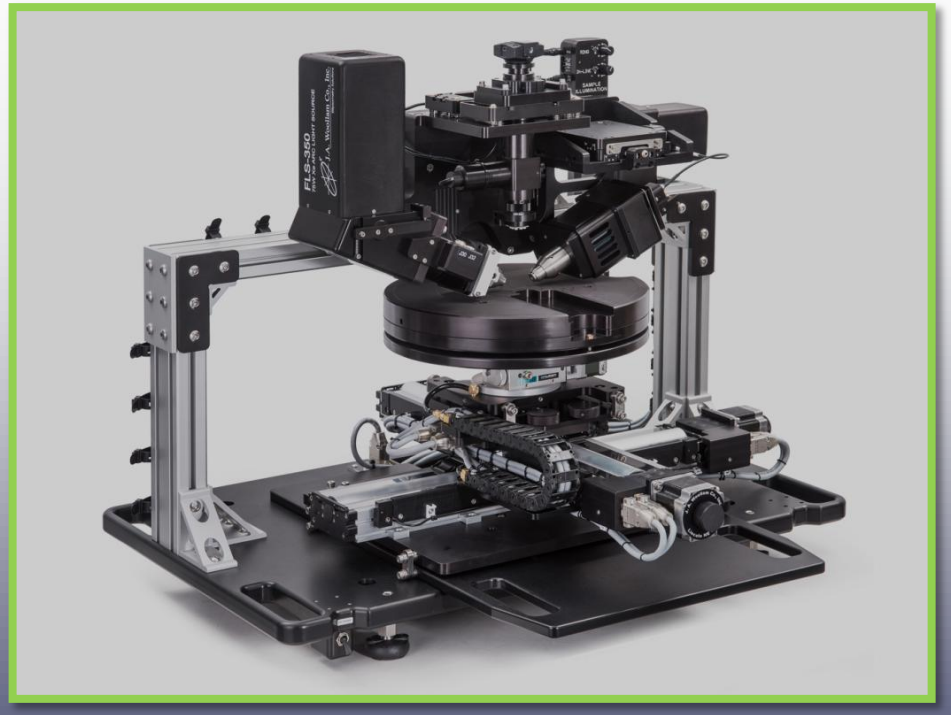
Penn State Nanofab

4 ALD tools: 2 thermal & 2 plasma



KJ Lesker
thermal 150LE

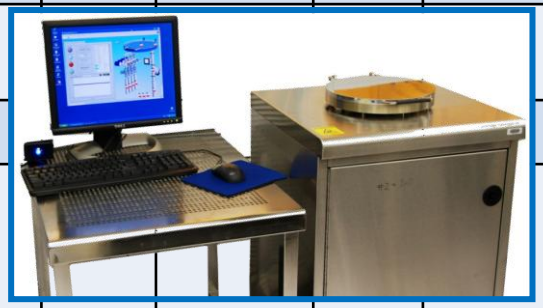
Thickness measurement and mapping



Woollam 2000X focused beam Ellipsometer

ALD processes on Savannah 200

	T (°C)	300	250	200	170	150	120	110	100	80	60	50
Regular chamber (6.5 mm tall)	Al_2O_3	0.85 /1.65	1.0 /1.65	1.03 /1.65	1.04 /1.63	1.08 /1.65			0.93 /1.55	0.96		0.82 /1.60
	HfO_2		1.14 /2.07	0.95 /2.02				1.16				
	TiO_2					0.44 /2.29				0.7		
	ZnO_2			1.35 /2.11			1.83			1.49	1.28	
	ZrO_2			0.97 /2.05								
	Ta_2O_5			0.55 /1.72								
	AZO											
Tall chamber (13 mm tall)	Al_2O_3			1.03 /1.64								

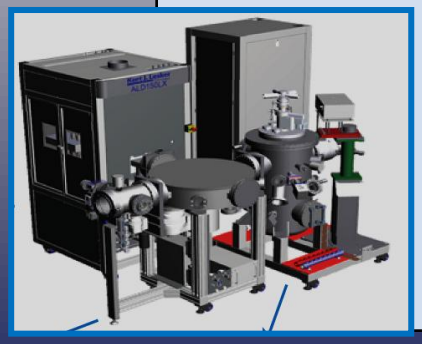


ALD processes on Lesker LE

	T (°C)	300	250	200	150	120	110	100
process	Al_2O_3	0.84 /1.61	0.88 /1.63	0.93 /1.66	0.96 /157		0.75 /1.57	0.76 /1.62
	HfO_2		0.97 /2.11	0.98 /2.05	1.10 /2.04			
	TiO_2				0.43 /2.00			
	Ta_2O_5	0.47 /1.75		0.53 /1.99	0.63 /1.98	0.78 /1.93		
Long water pulse(1.6s)	Al_2O_3			1.06	1.03 /1.61		0.78 /1.6	0.93 /1.66
EXPO	Al_2O_3			1.22				
	Ta_2O_5			0.65 /2.03				

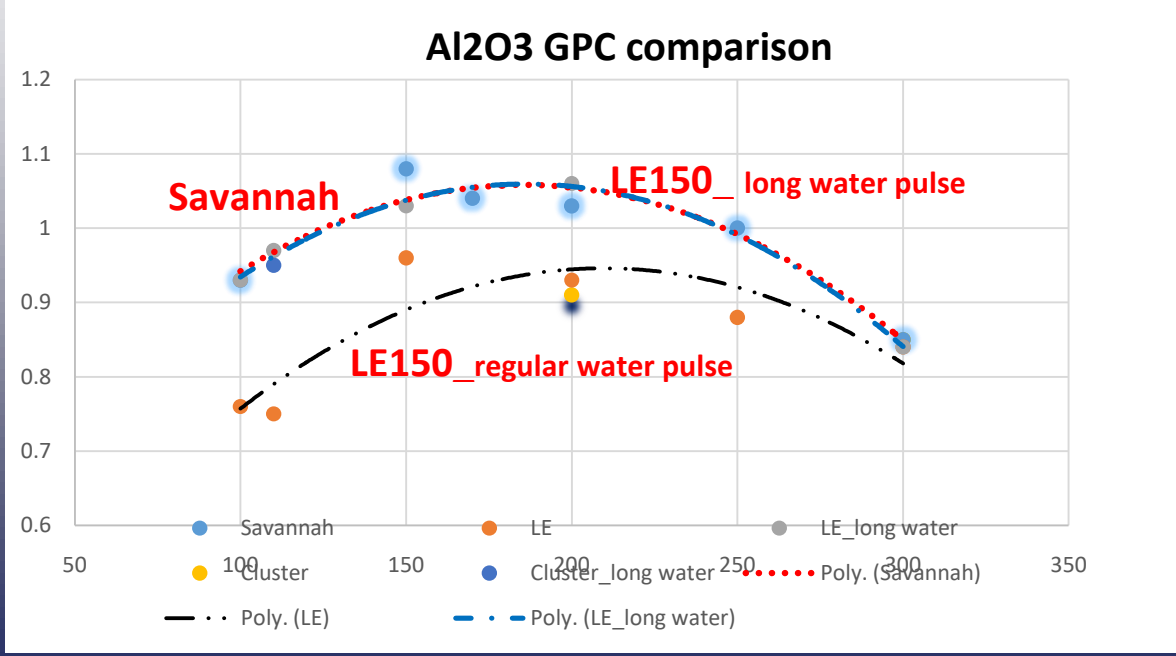
ALD processes on Lesker Cluster LX150

	T (°C)	350	300	250	200	120	110	100
Thermal	Al_2O_3		0.85 /1.64		0.91 /1.65			
Long water pulse(1.6s)	Al_2O_3						0.95 /1.6	
Plasma process	Al_2O_3		0.84 /1.63		1.06 /1.66			
	HfO_2				1.09 /2.02	1.23 /2.00		
	SiO_2		0.96 /1.41					
	TiN	0.40 /165 μΩ cm	0.41 /379 μΩ cm					
	AlN			0.58 /1.96	0.69 /1.93			
	GaN							1.14 /1.86
	Pt		0.6-0.8 /11 cyl (Nucl delay)					

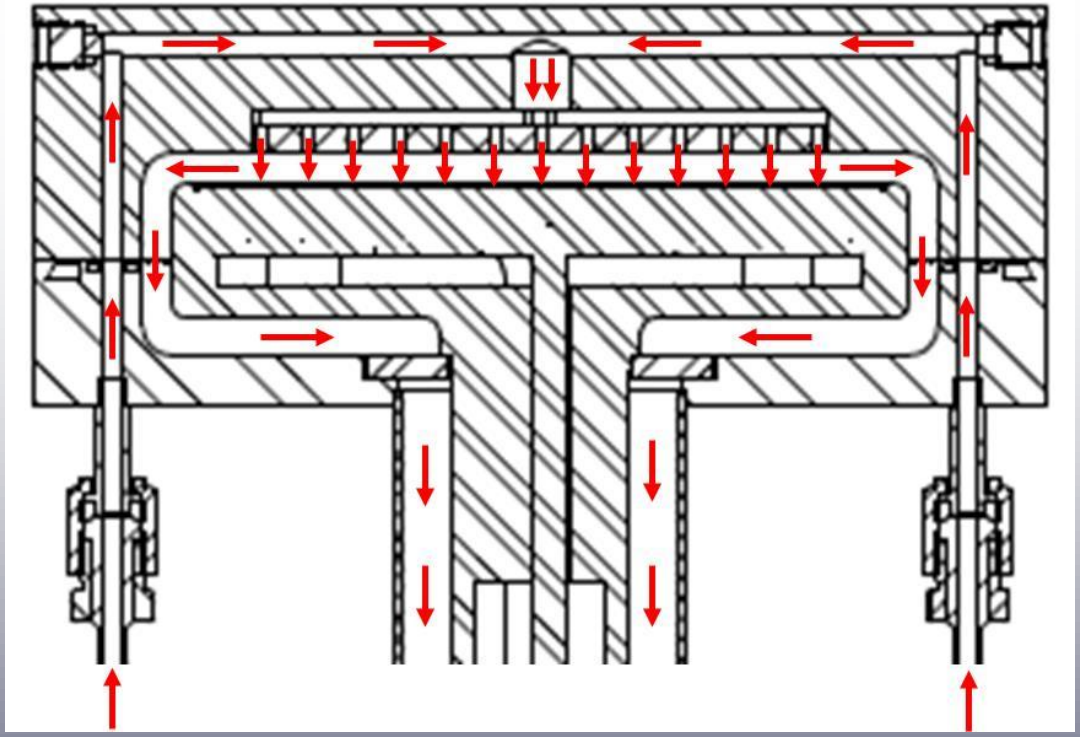


Comparison between different systems

	T (°C)	Savannah thermal	LE thermal	Cluster thermal	Cluster Plasma
Al2O3	300	0.85	0.84	0.85	0.84
	200	1.03	0.93		1.06
HfO_2	200	0.95	0.98		1.09
Ta_2O_5	200	0.55	0.53		
TiO2	150	0.44	0.43		



Different gas flow design from Savannah



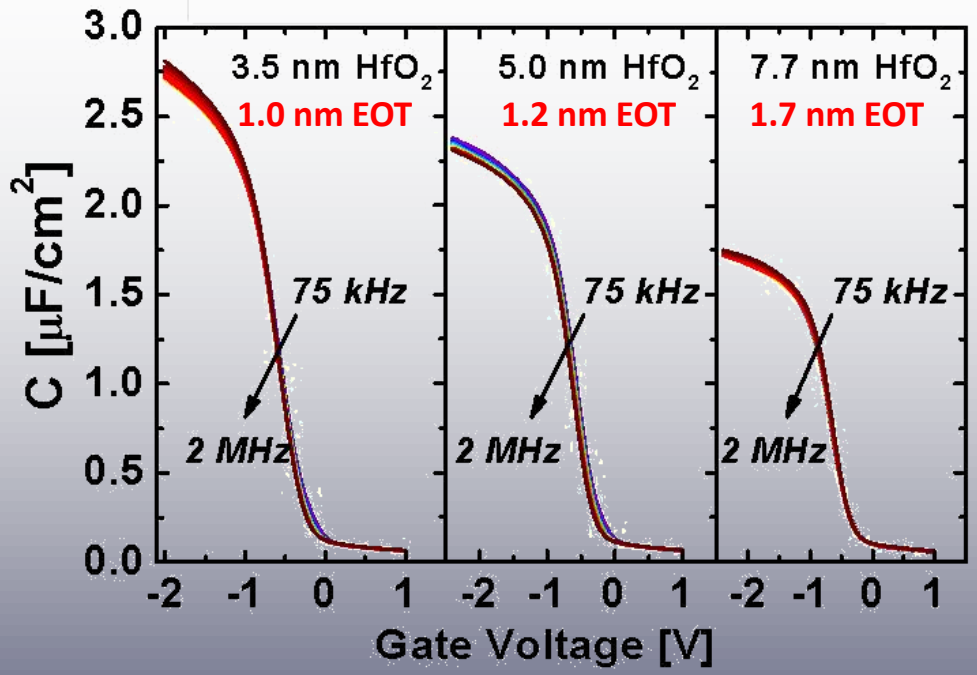
Input Port #1

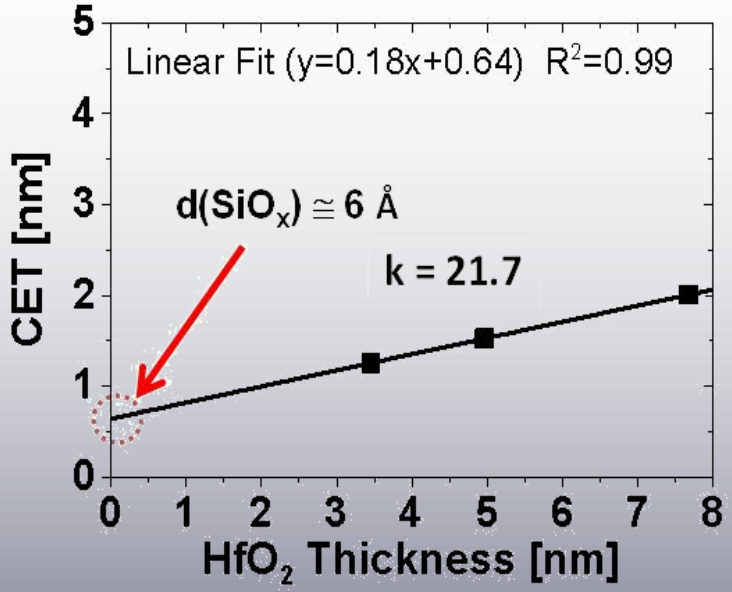
H2O

- Inactive gas flow is continuous, viscous and laminar – precursor gas/vapor periodically pulsed through
- Net direction of flow is perpendicular to substrate surface

CV measurement of MOSCAP for HfO2

with thicknesses of 1.0, 1.2 & 1.7 nm EOT



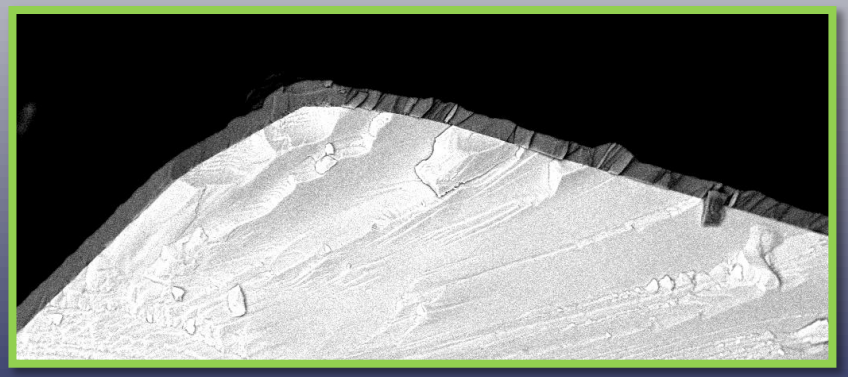


Steep slope & small frequency dispersion indicative of very low interface trap density ($D_{it} < 10^{11}$ cm^{-2} eV^{-1})

Indicating a high dielectric constant (k ~22) and thin interfacial oxide thickness (~0.6 nm) required for aggressive device scaling (1 nm EOT)

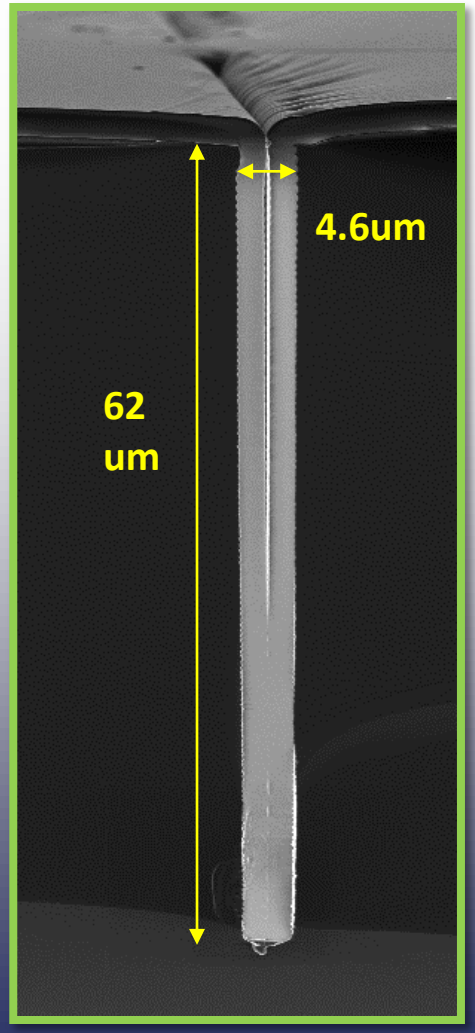
How thick a cylinder of 25 gram TMA can deposit Al2O3 film on Savannah?

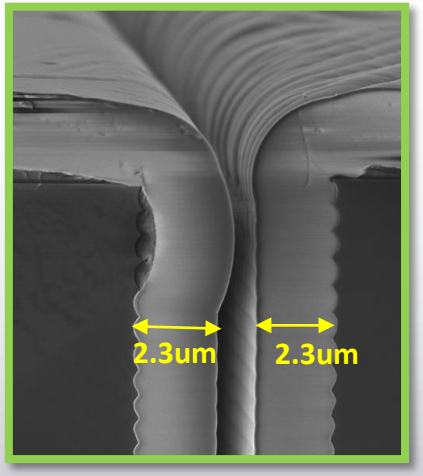
8 um

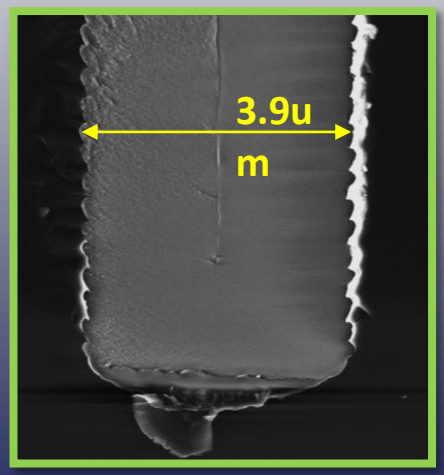


1 um Al_2O_3 on fiber

Regular thermal Al_2O_3 process on Savannah



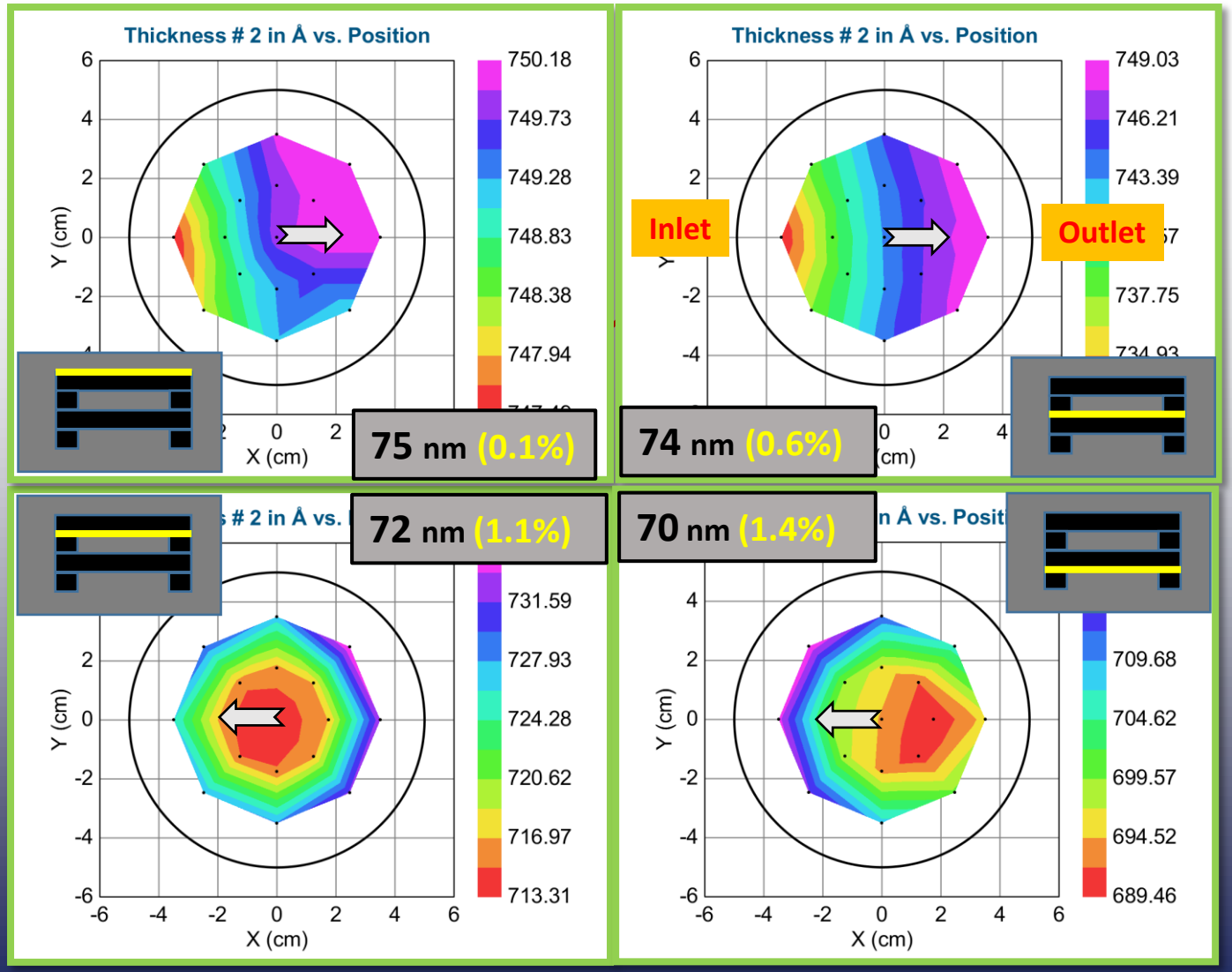




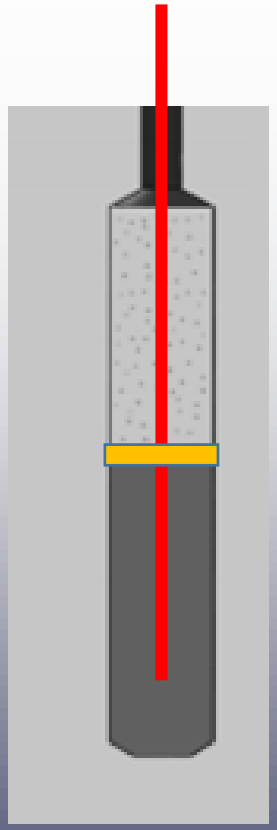
Aspect ratio can be larger than 100:1!

Coating multiple wafers on Savannah

Al2O3 170C
700 cycles
2X 4”
double side polished
Si wafers
Si spacer: 0.7mm



Precursor overtemperature damage



Tetrakis(dimethylamido)zirconium, TDMAZr,

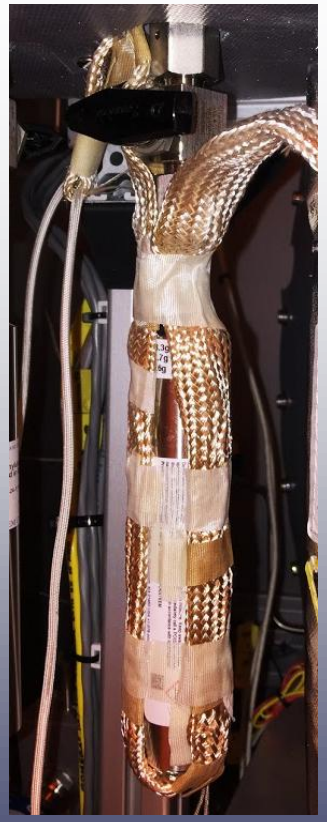
Tetrakis(dimethylamino)tin(IV)

Pentakis(dimethylamido)tantalum

TDMAZr forms a yellowish thin crust on top when overheated
The precursor can be reused when poking through the crust

Better temperature control

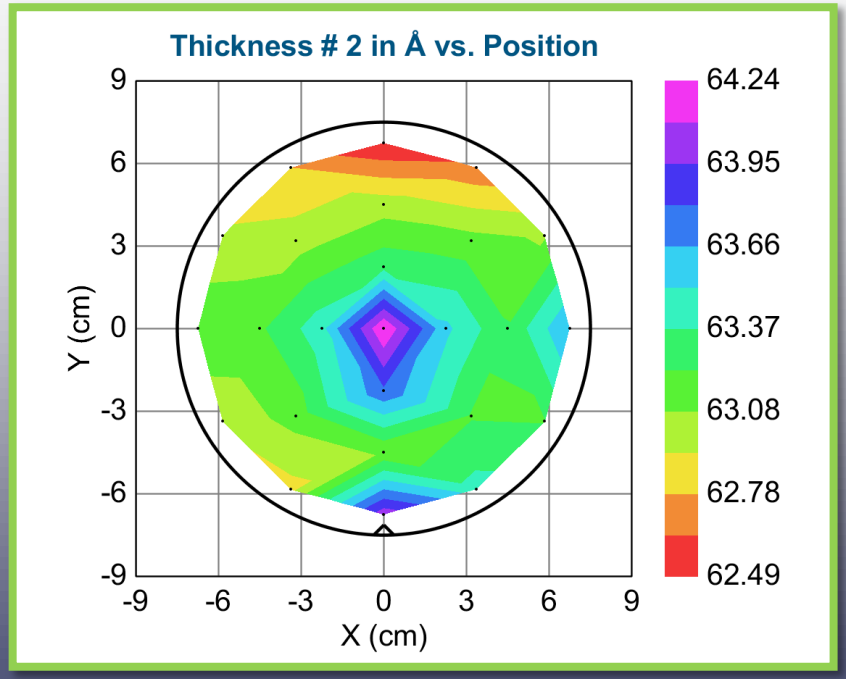
using self adhesive thermocouple & heating tape



Stable Ta_2O_5 process

Ta_2O_5 static 200C 100 cycles

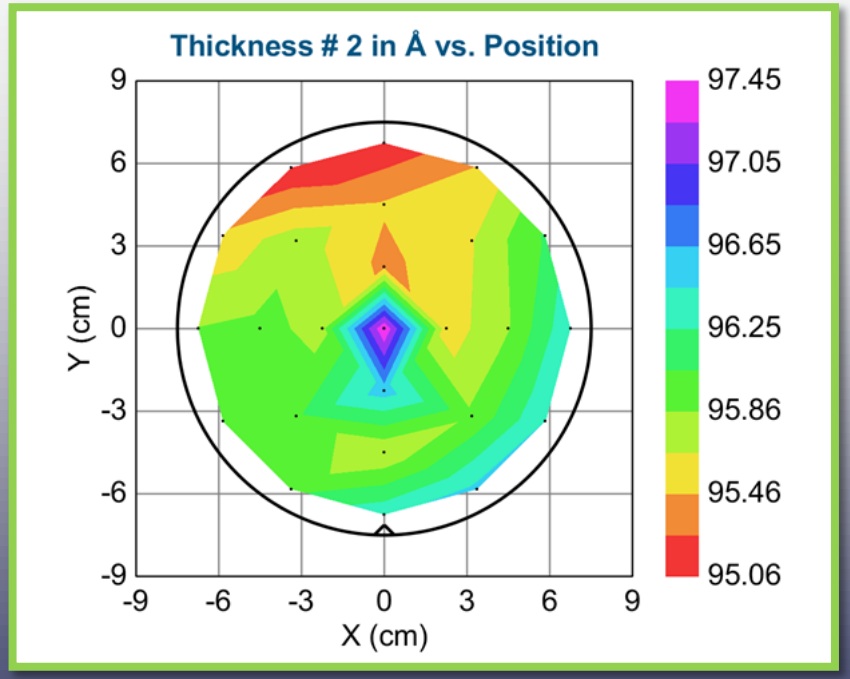
GPC: 0.63 A/cycle
Substrate: 150 mm Si
Native oxide: 1.15 nm
180911



<d>: 63.23 ± 0.4 A (0.6% uniformity)

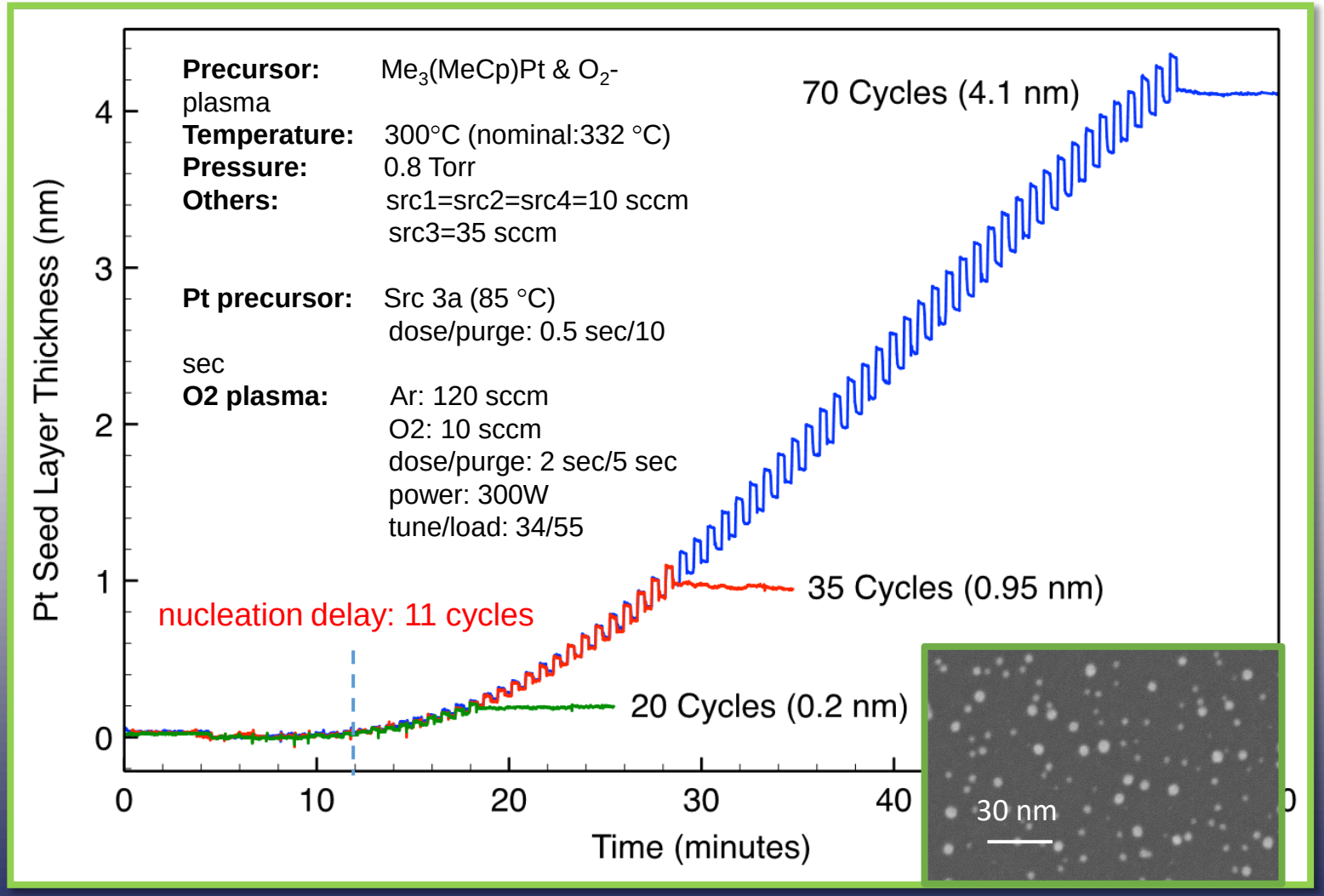
Ta_2O_5 static 200C 150 cycles

GPC: 0.64 A/cycle
Substrate: 150 mm Si
Native oxide: 1.15 nm
190605



<d>: 95.9 ± 0.5Å (0.5% uniformity)

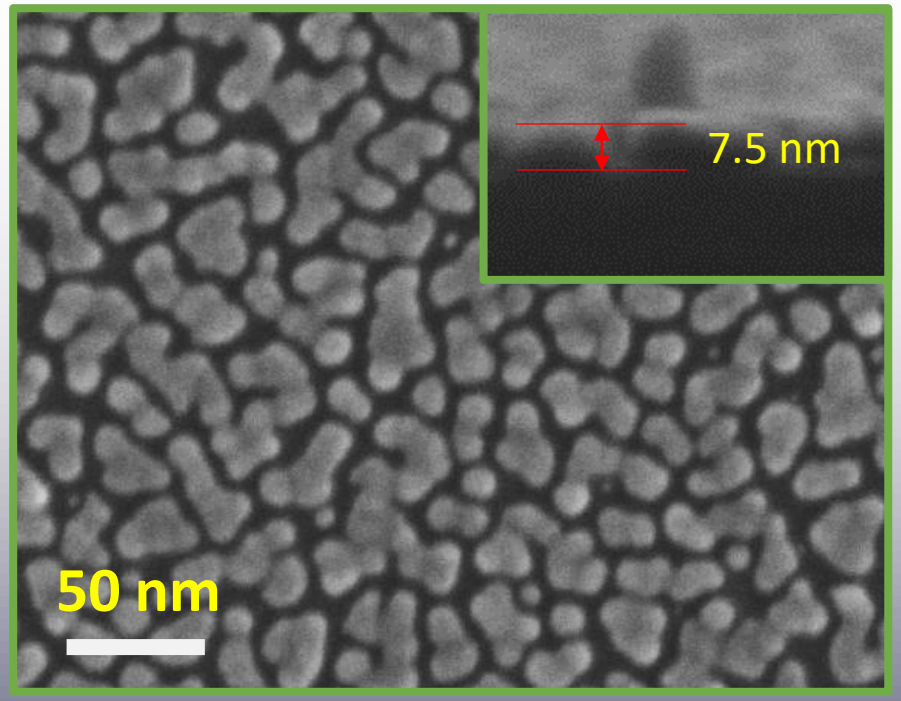
PEALD Pt process

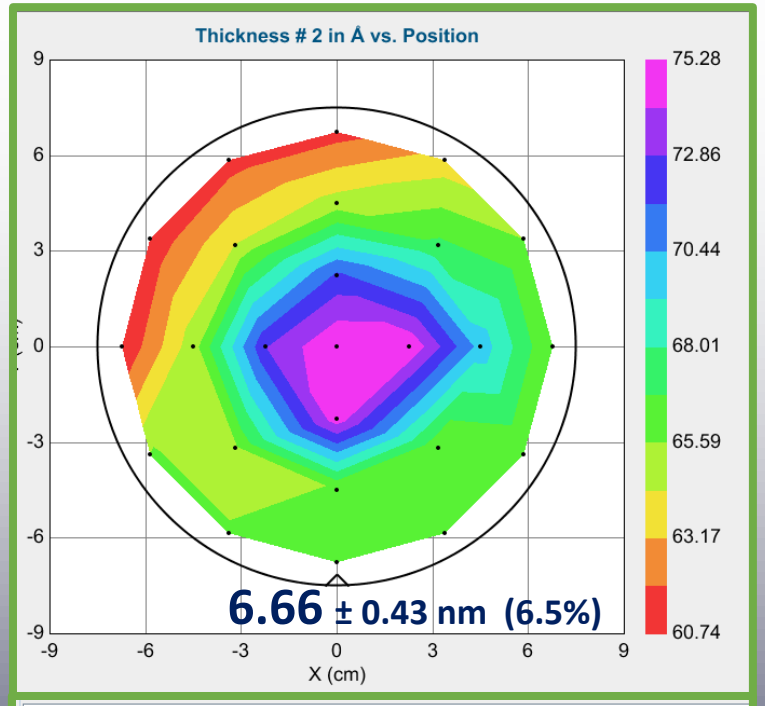


Curtesy: Bruce Rayner-KJ Lesker

Thickness measurement of Pt film

100 cycles of Pt deposition



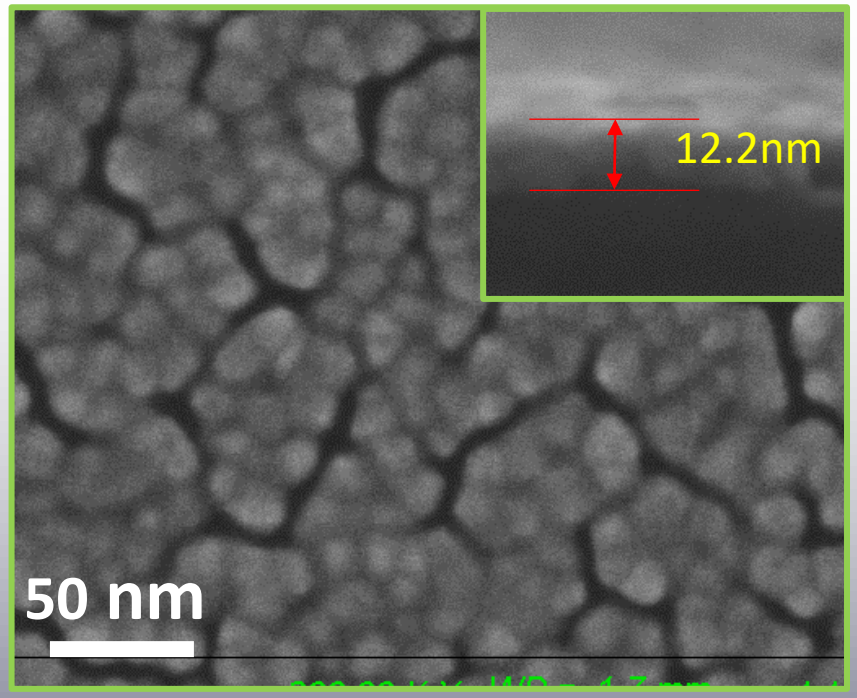


Layer Commands: Add Delete Save
Include Surface Roughness = OFF
Layer # 2 = Gen-Osc Thickness # 2 = 117.96 Å (fit)
Add Oscillator Show Dialog Fast Gaussian Calc = ON
Einf = 2.387 (fit)
UV Pole Amp. = 0.0000 UV Pole En. = 11.000
IR Pole Amp. = 0.0000
Fit All Clear All Add Amp. Add Br. Add En.
1: Type = Drude(RT) Resistivity (Ohm·cm)1 = 0.00023159 (fit) Scat. Time (fs)1 = 0.518 (fit)
2: Type = Lorentz Amp2 = 0.640632 (fit) Br2 = 0.1750 (fit) En2 = 3.126 (fit)
3: Type = Lorentz Amp3 = 4.595097 (fit) Br3 = 3.2924 (fit) En3 = 7.030 (fit)
4: Type = Lorentz Amp4 = 3.111312 (fit) Br4 = 2.6162 (fit) En4 = 5.071 (fit)
Layer # 1 = NTVE_JAW Native Oxide = 11.80 Å
Substrate = SI_JAW

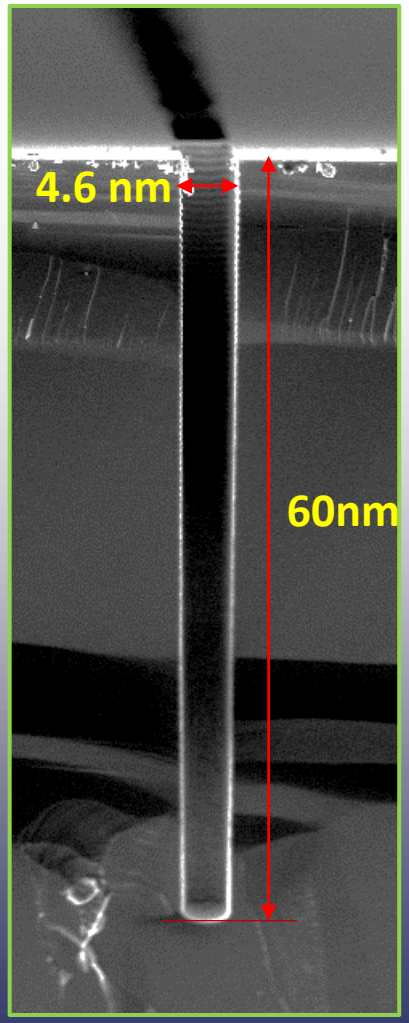
Drude model

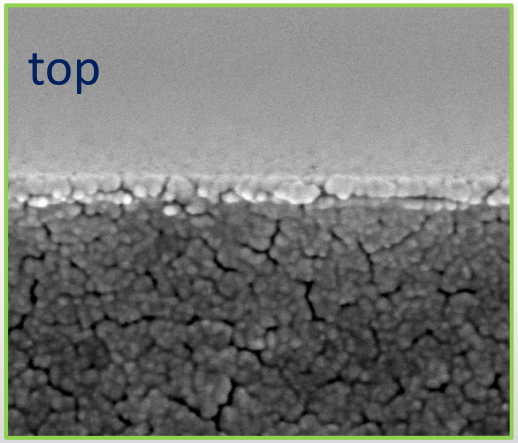
good for conductive film: Pt & TiN

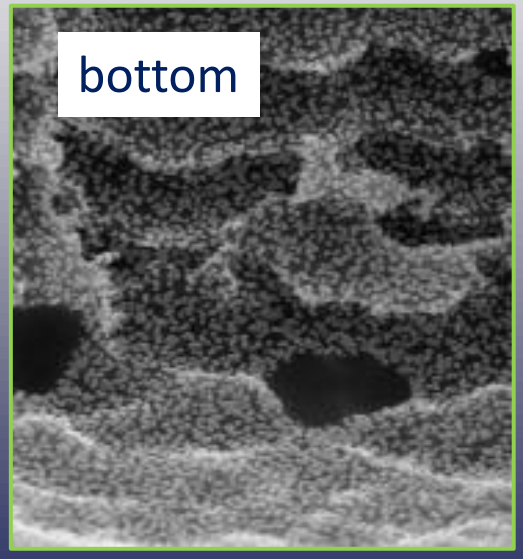
200 cycle Pt deposition on Si & trenches



ellipsometry 11.9 nm

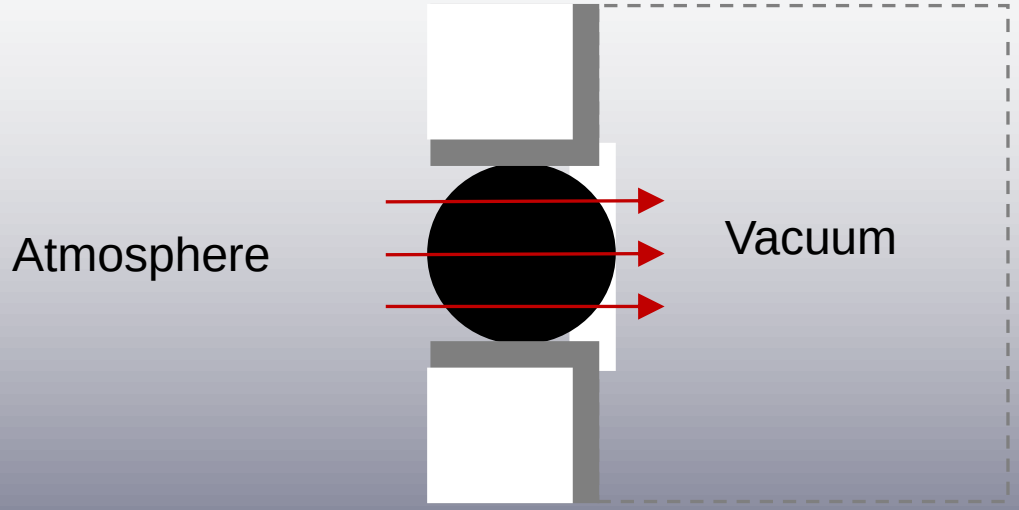






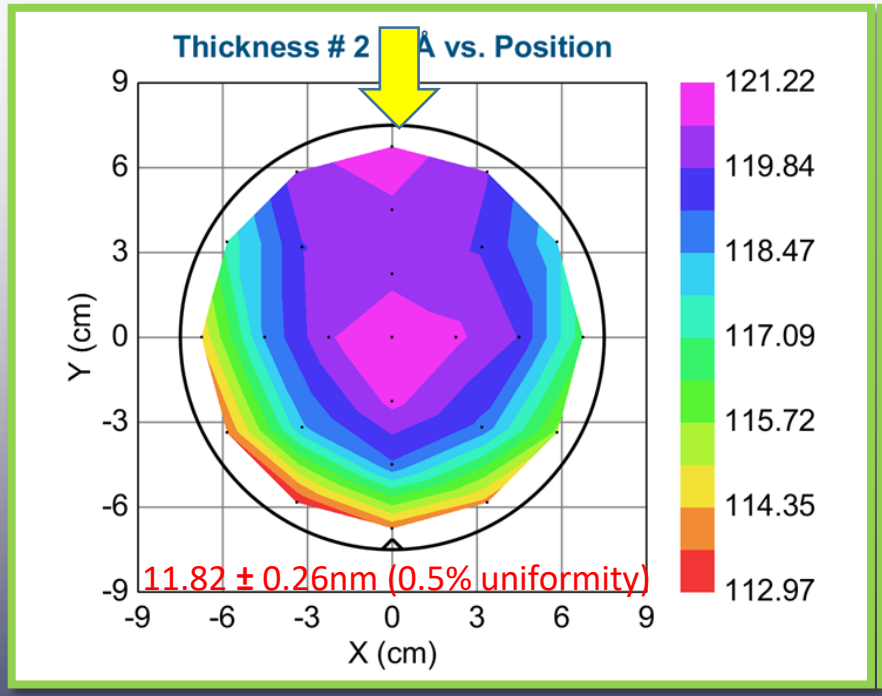
Bottom has less deposition than top

Does Permeation through O-ring affect ALD process?



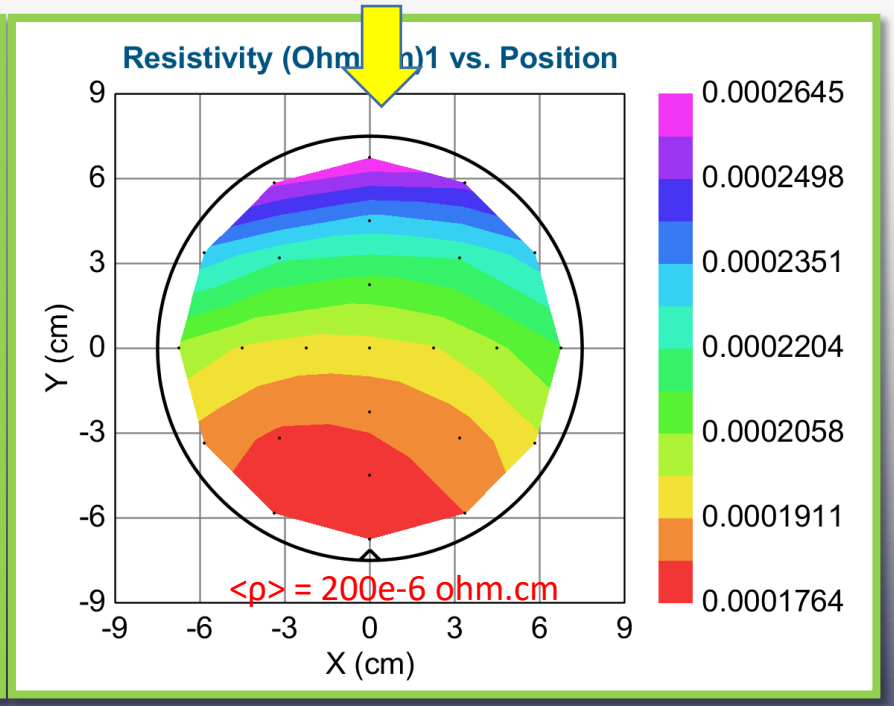
TiN thickness mapping shows gradient related to air permeation

Air permeation



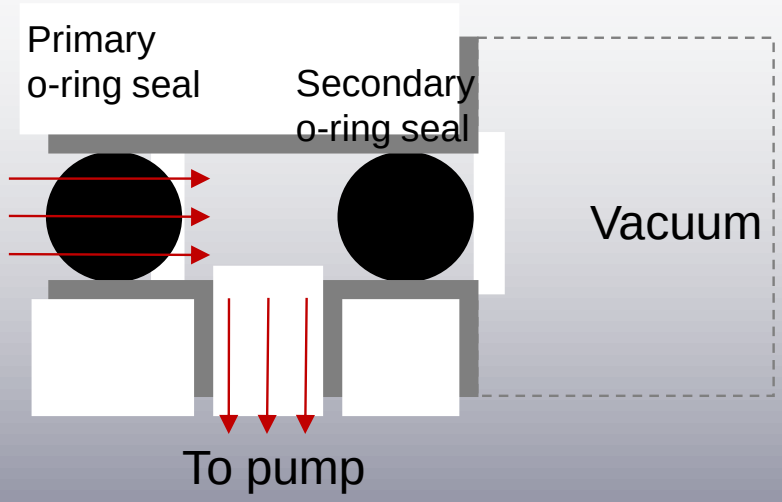
975W, 300 cycles, 300C
GPC: **0.394 Å/cycle**
Substrate: 150 mm Si
Native oxide: 1.18 nm

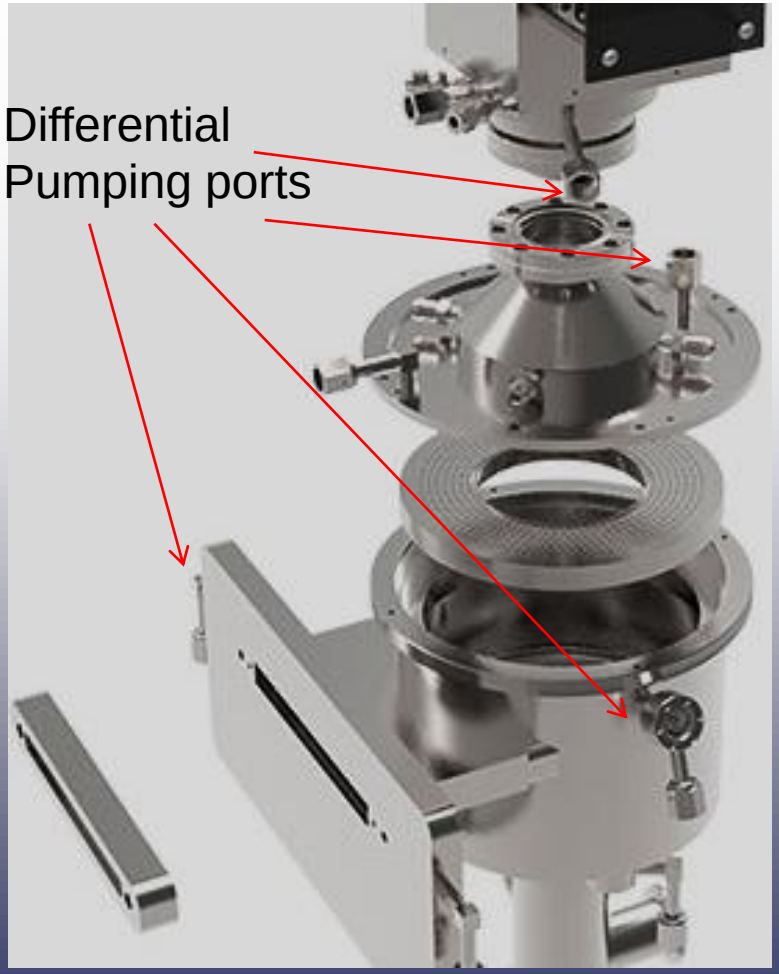
Air permeation



TiCl4 + H2:N2 plasma (3:1 ratio)
Process Pressure: ~1.150 Torr
Substrate heater temperature: 400C (~321C using carrier)
TiCl4 Dose/purge: 0.1 sec/3 sec
Plasma Dose/purge: 9 sec/5 sec
Cycle Time: ~17 seconds

Solution: Double O-rings & differential pumping

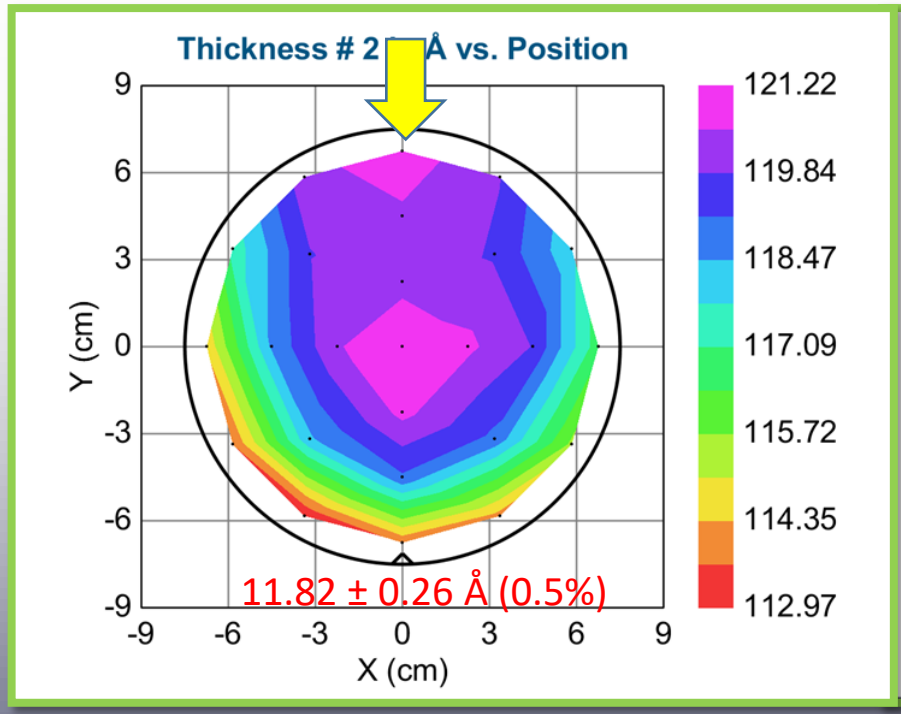




Curtesy: Bruce Rayner-KJ Lesker

Effect of differential pumping on TiN growth

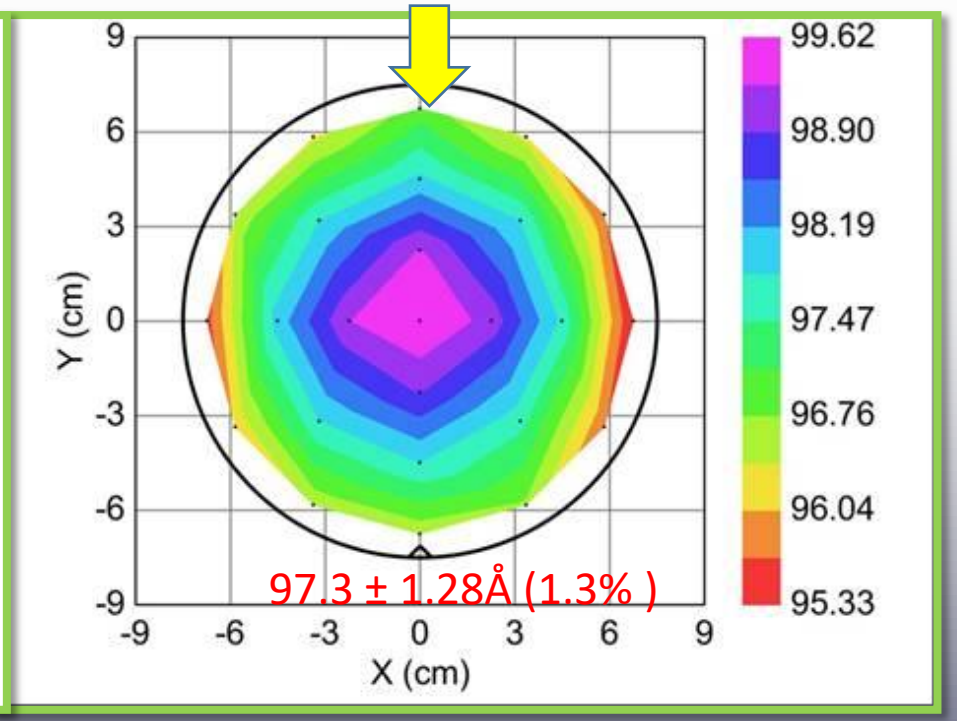
Air permeation



GPC: 0.39 Å/cycle

w/o differential pumping
(Cluster LX150)

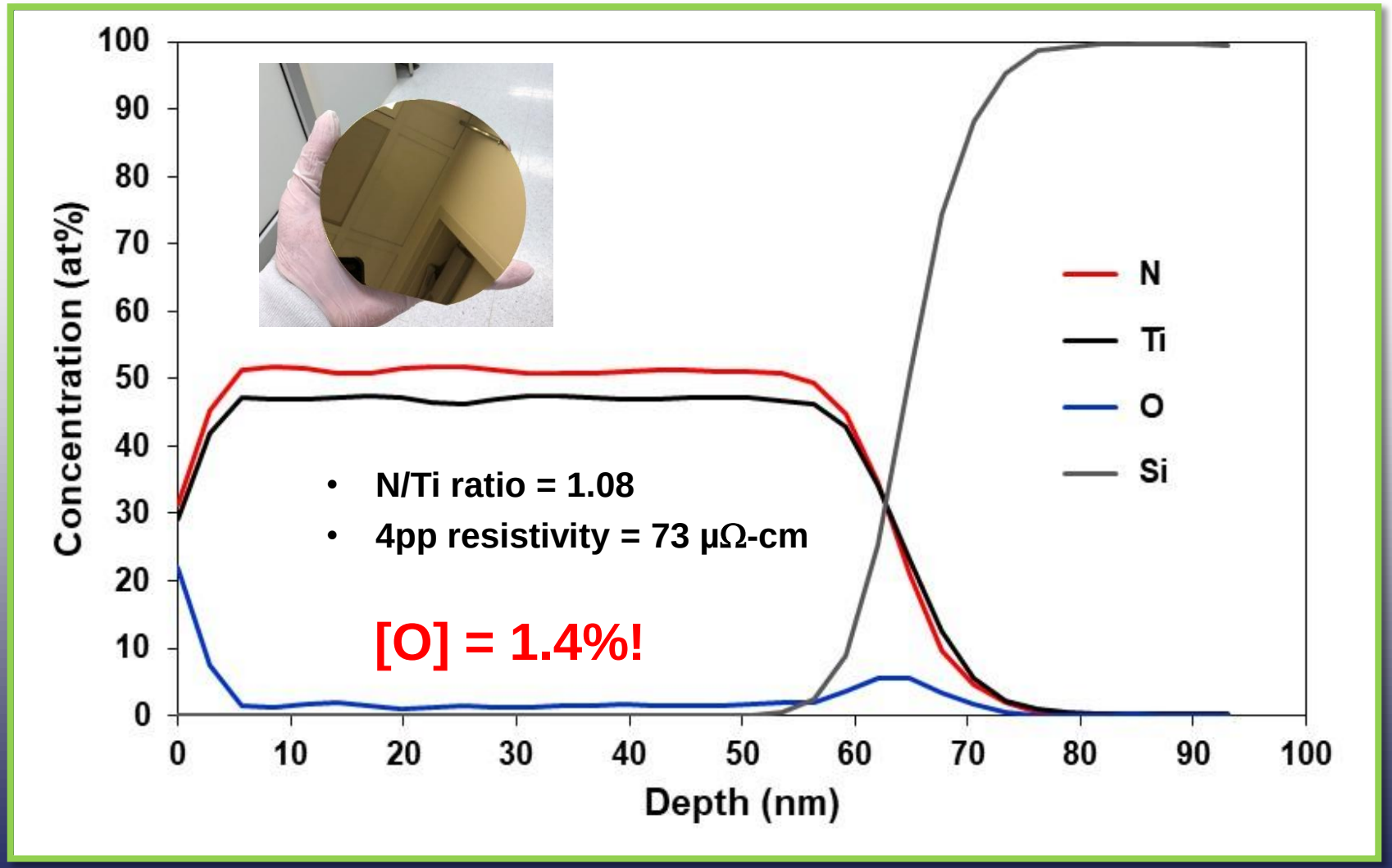
Air permeation



GPC: 0.32 Å/cycle

w/ differential pumping
(LX150)

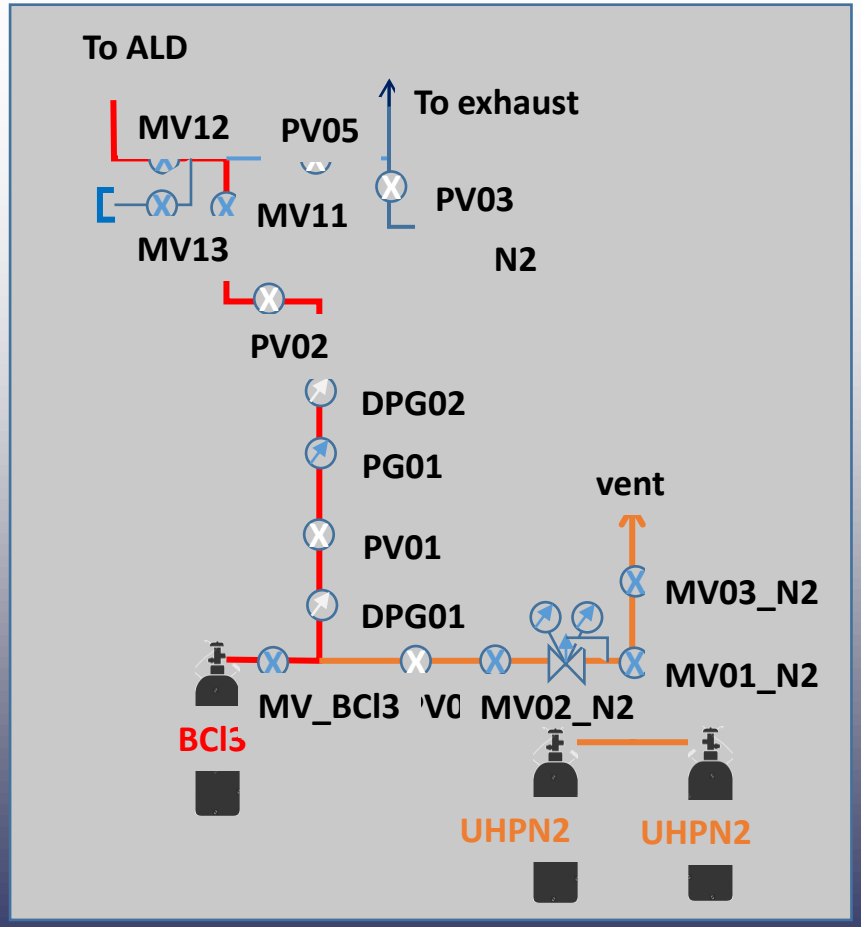
XPS confirms extremely low O in TiN



Curtesy: Bruce Rayner-KJ Lesker

BCl3 gas delivery system for BN deposition

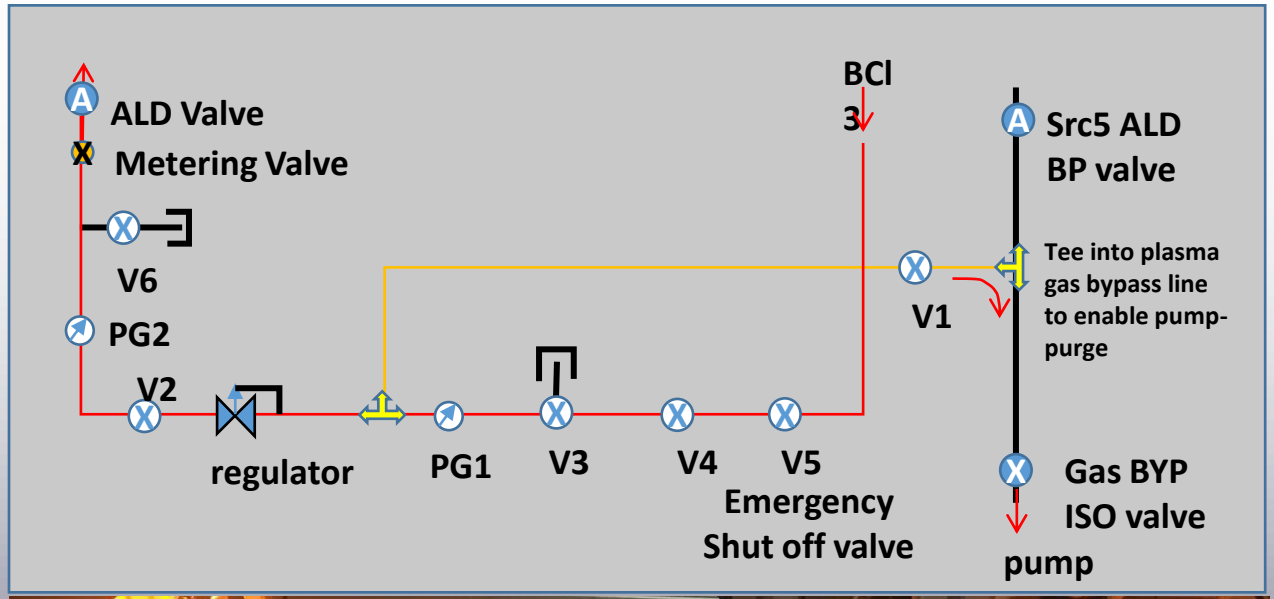
BCl3: toxic & corrosive



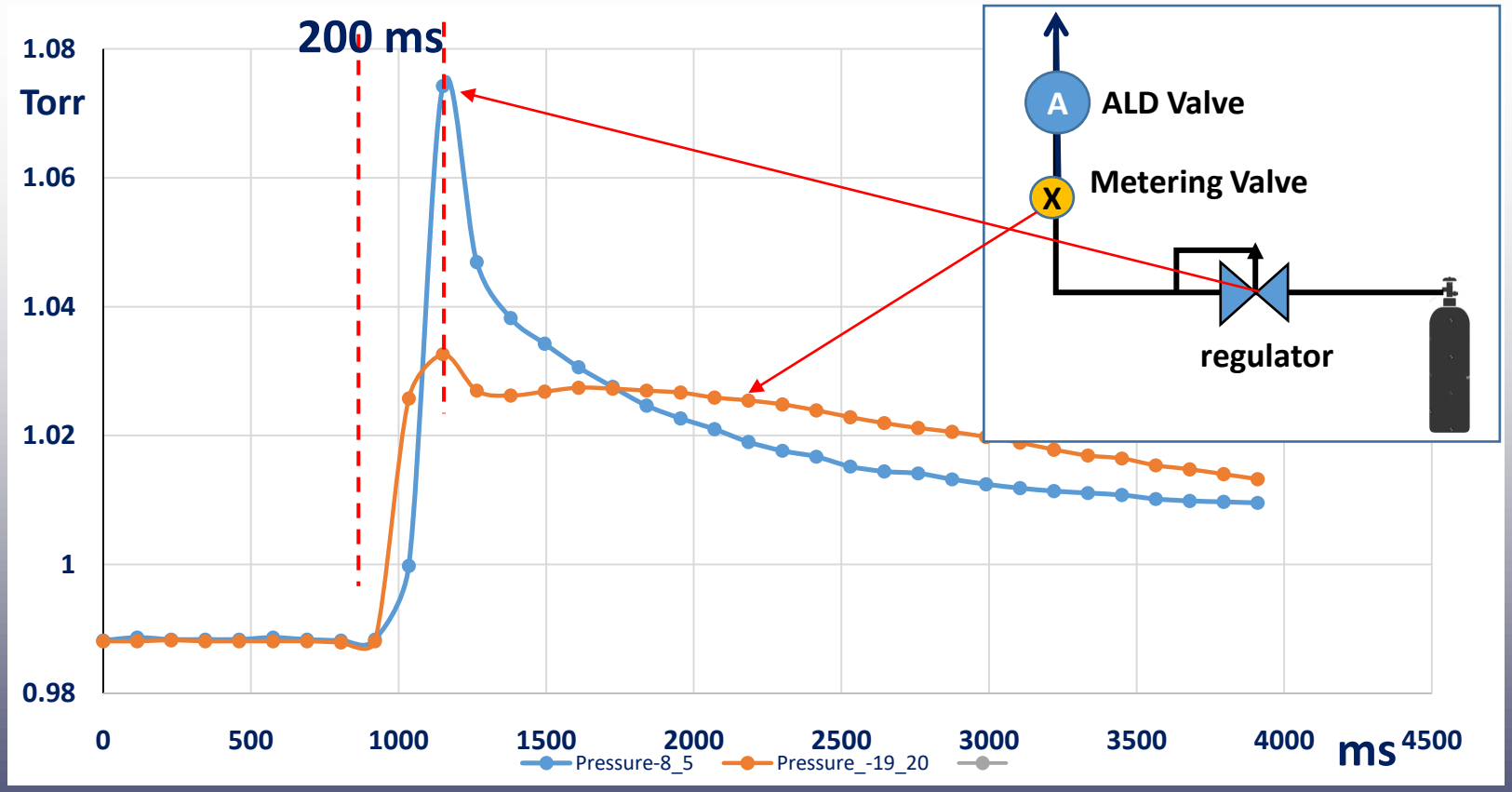
Gas delivery in basement

BCl_3 gas delivery system for BN deposition

Gas delivery on tool



Pulse height tuning using N_2



Peak height is controlled by regulator

Steady sate flow is controlled by metering valve

Thank you!