EE412 Final Presentation

Developing a standard recipe of thermal ALD Tantalum Pentoxide(Ta_2O_5) film

06/06/2014

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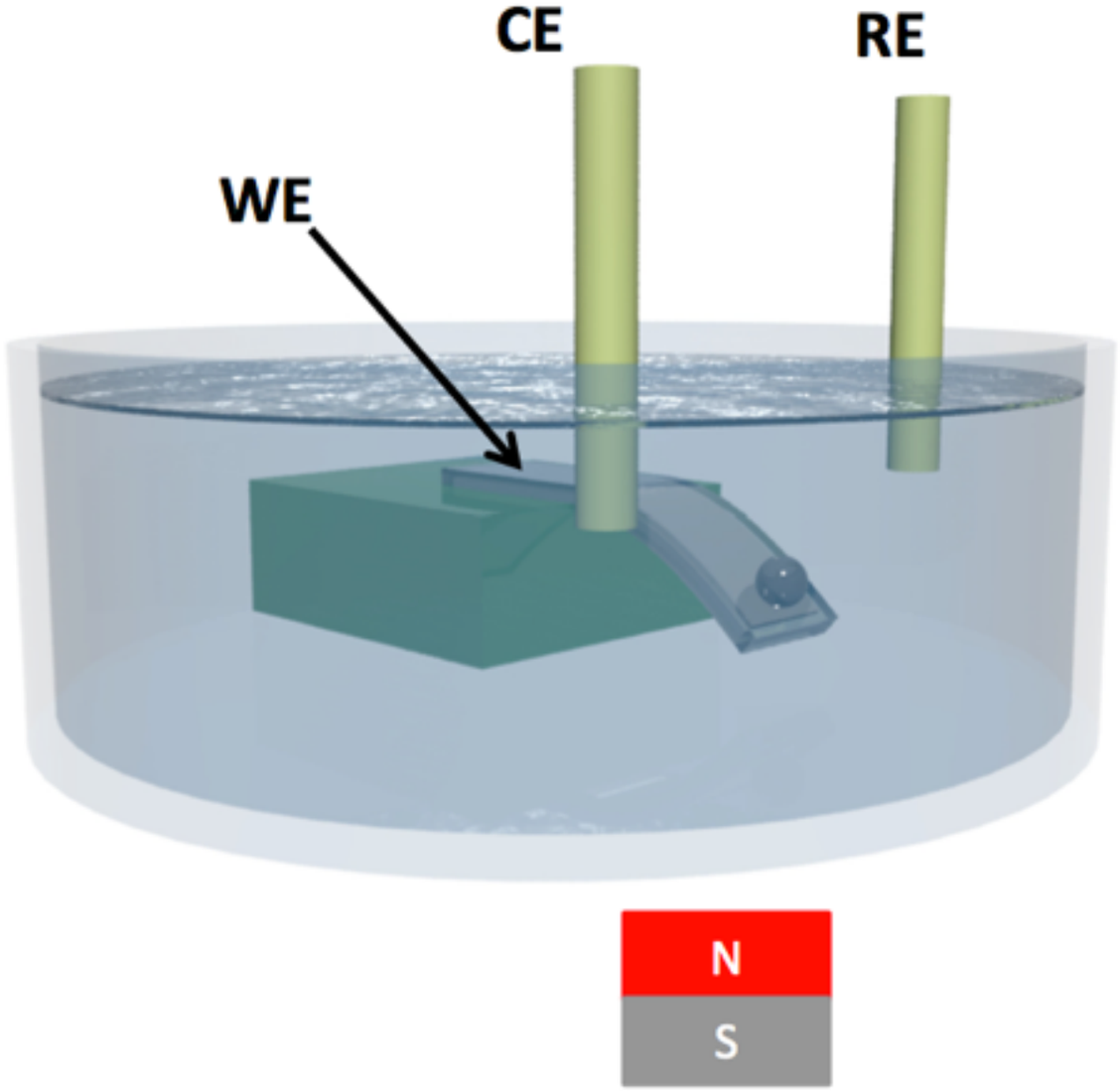
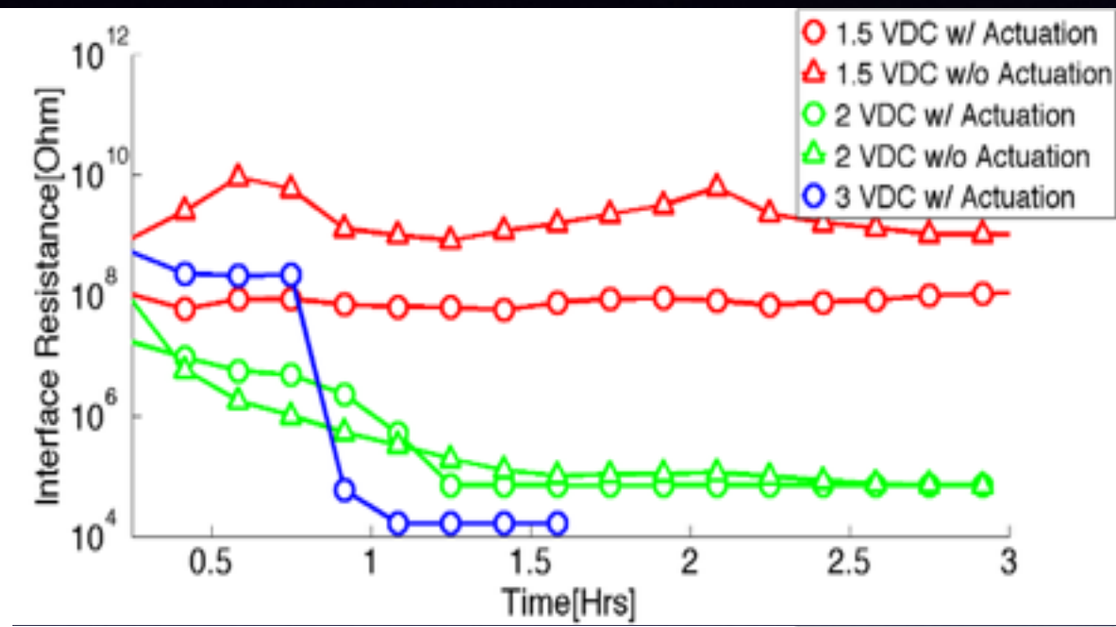
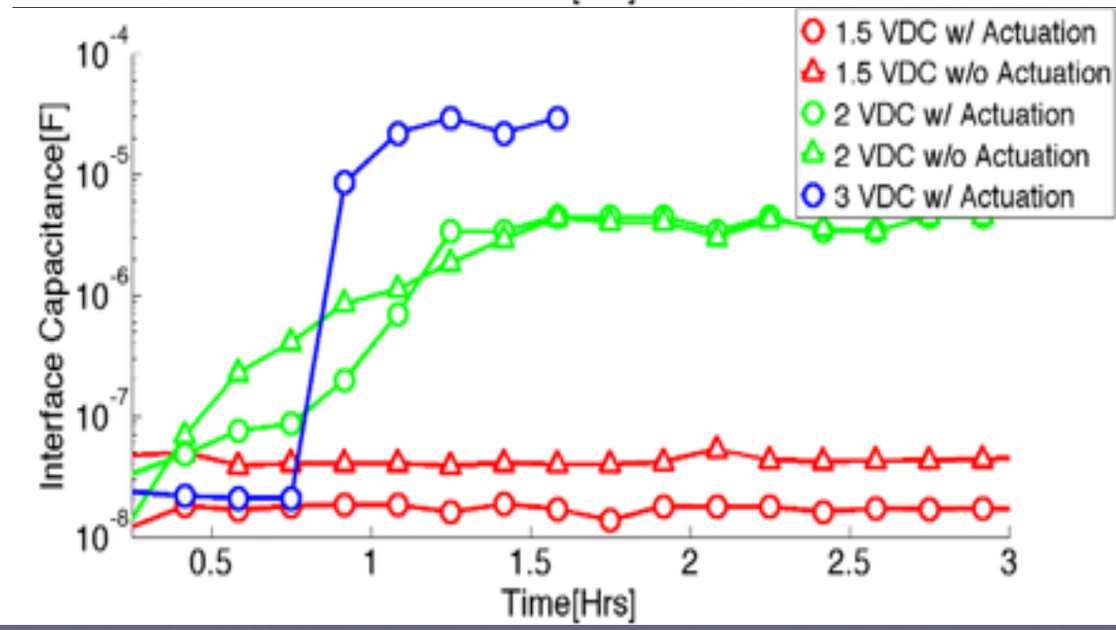
Contents

I. Introduction

Motivation of studying ALD Ta_2O_5



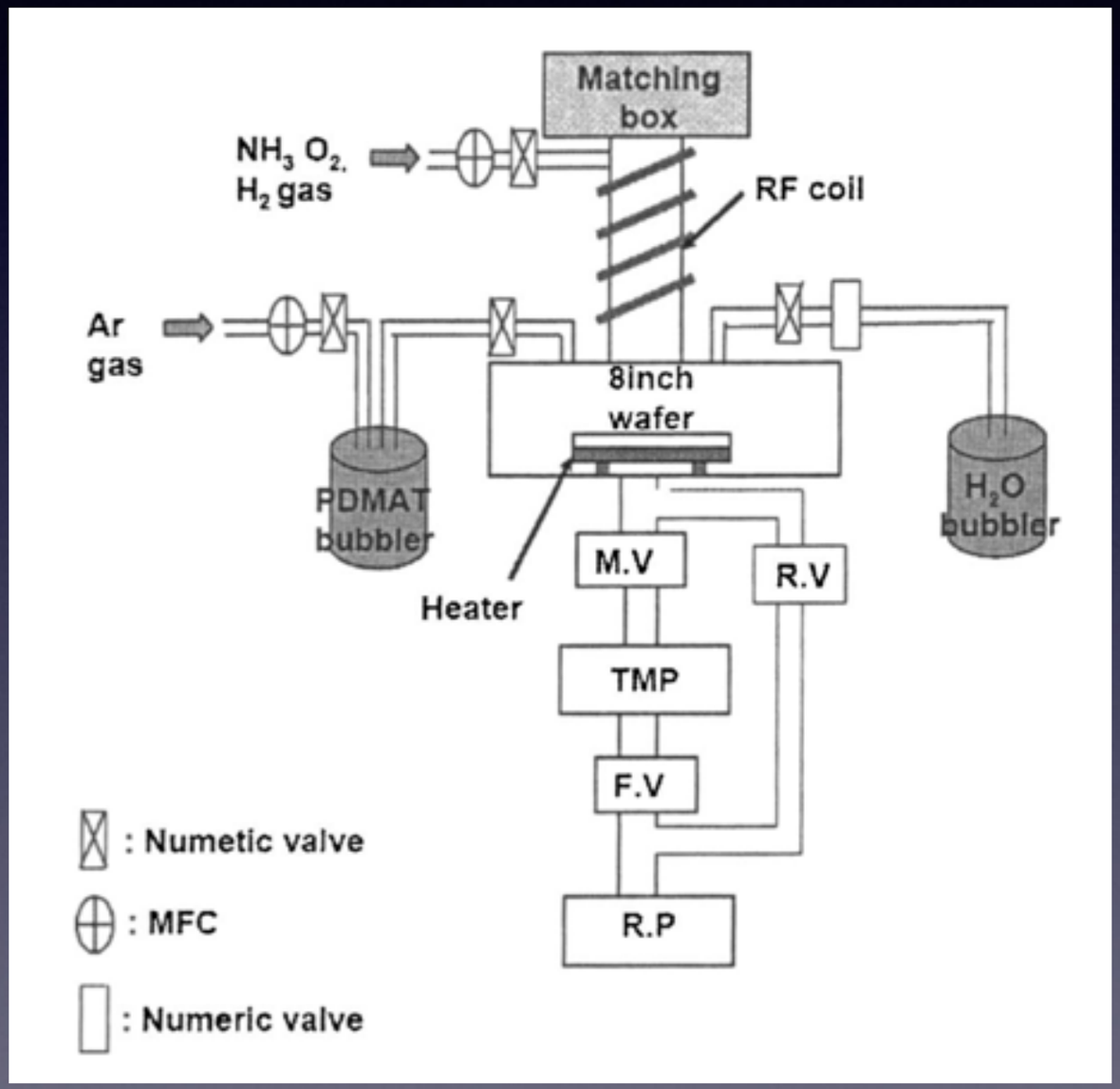


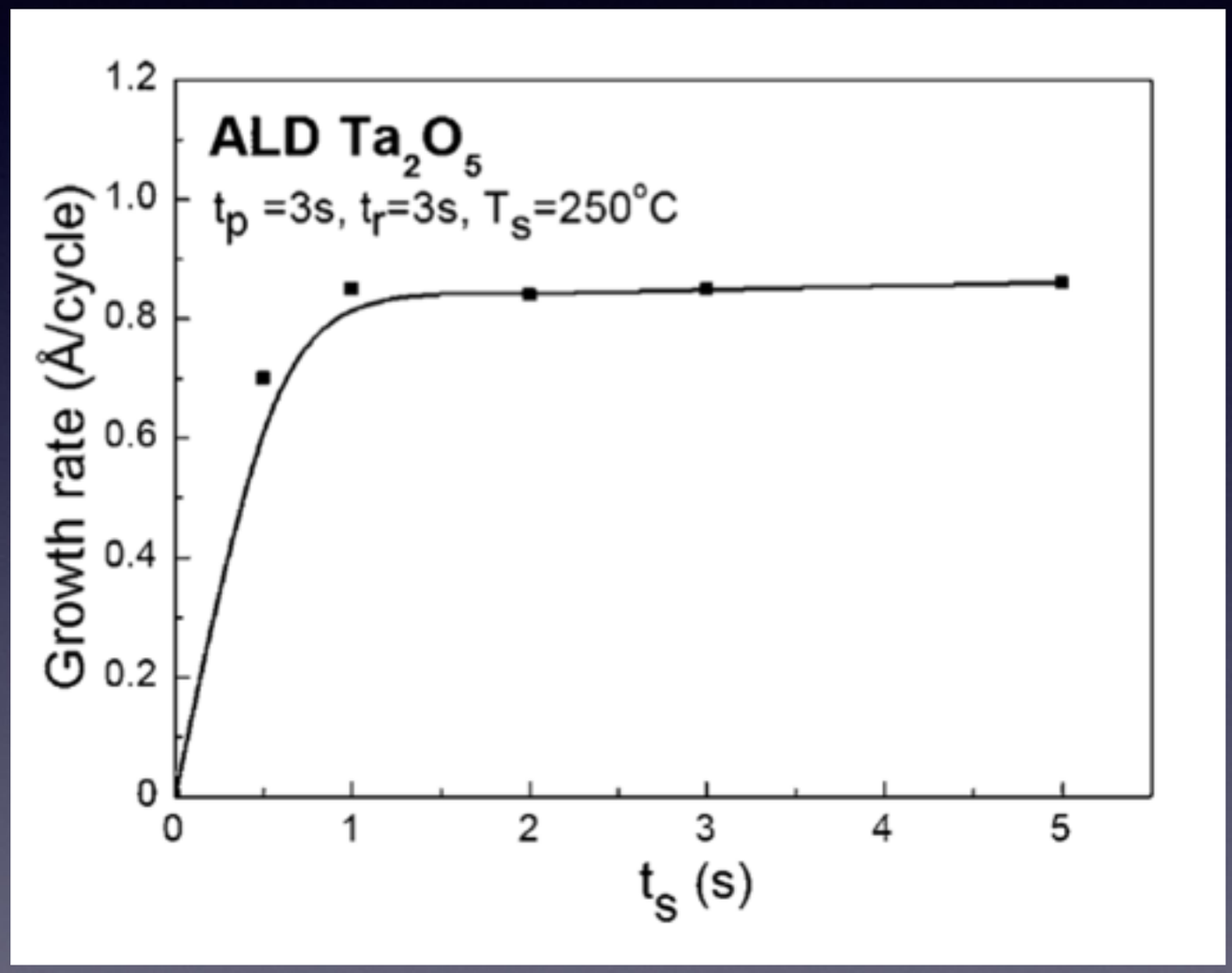


Prior art of ALD Ta_2O_5 recipes

Precursor: $Ta[N(CH_3)_2]_5$ or PDMAT

Thermal ALD



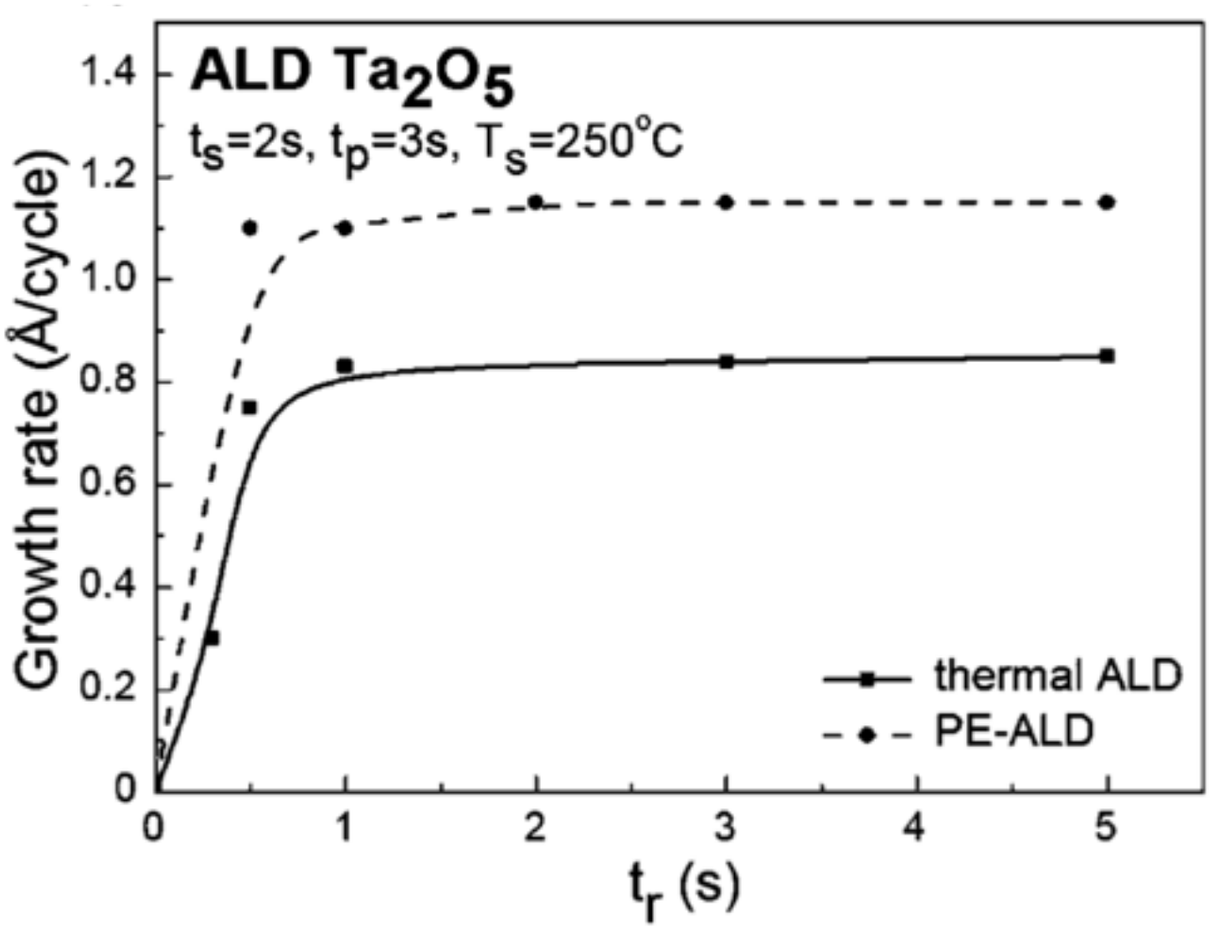


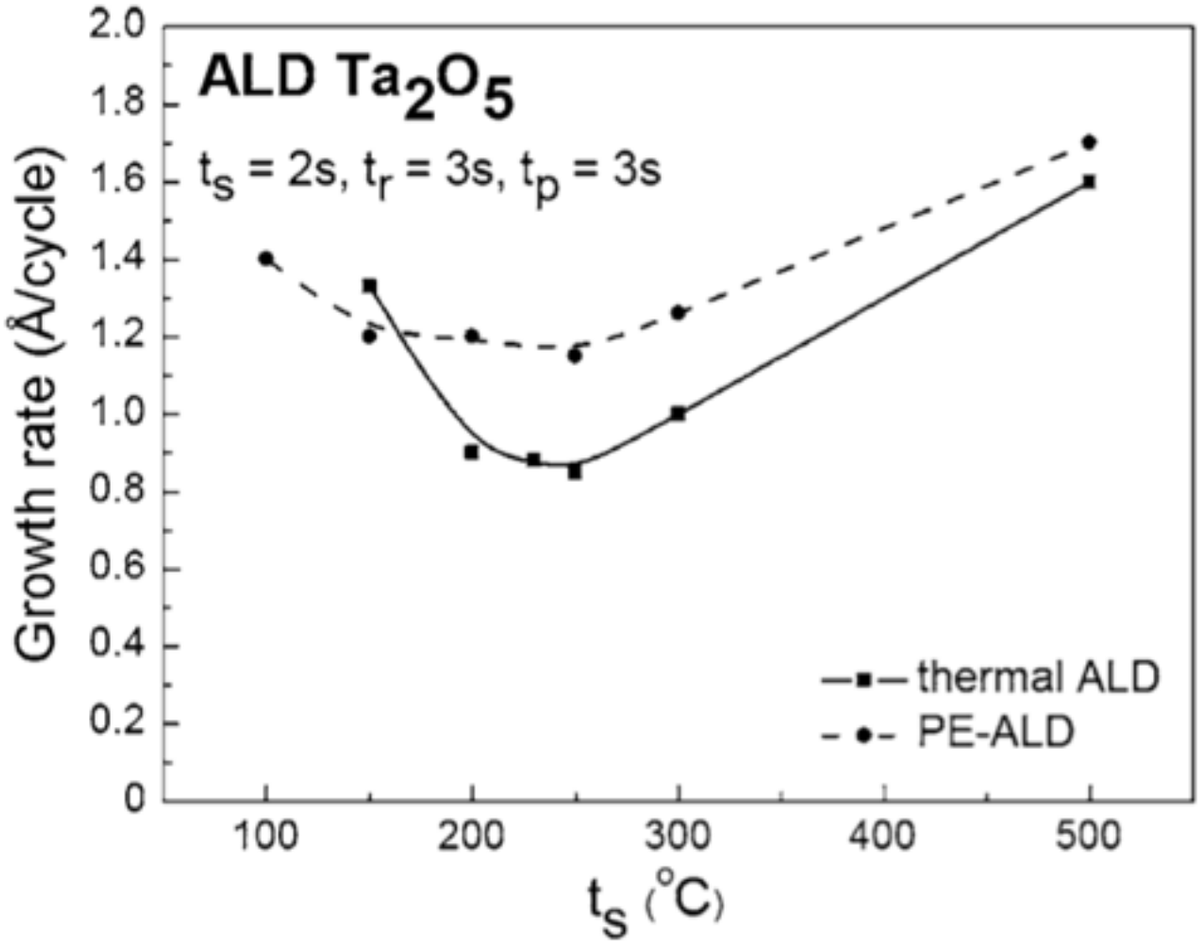
W.J. Maeng, S.J. Park, H. Kim, *J. Vac. Sci. Technol. B*, 2006

Prior art of ALD Ta_2O_5 recipes

Precursor: $Ta[N(CH_3)_2]_5$ or PDMAT

Thermal ALD





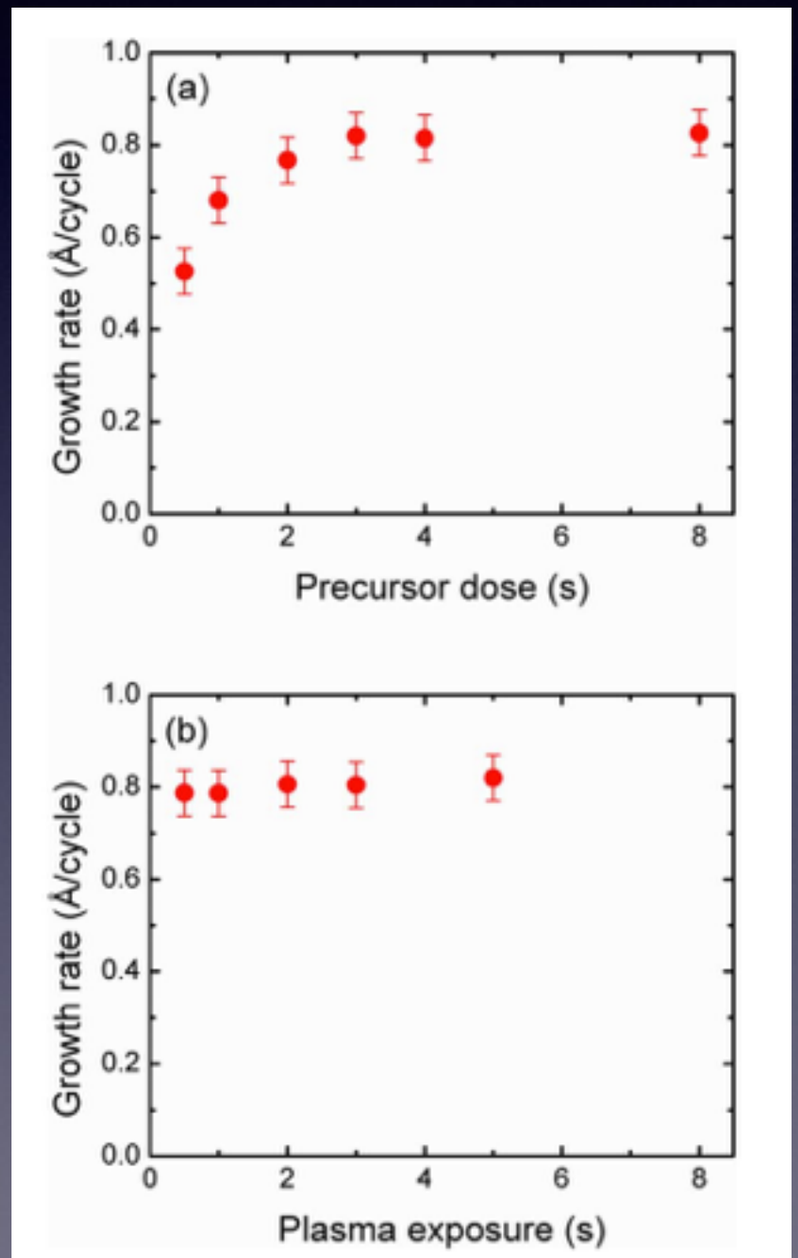
W.J. Maeng, H. Kim, *Electrochemical and Solid-State Letters*, 2006

Prior art of ALD Ta_2O_5 recipes

Precursor: $Ta[N(CH_3)_2]_5$ or PDMAT

Plasma Enabled ALD

Parameter	Standard Setting	Range varied
PDMAT dose time	3.0 s	0.5 - 8 s
Ar partial pressure	30 mTorr	
Plasma exposure time	2.0 s	0.5 - 5 s
O2 partial pressure	7.5 mTorr	
Plasma Power	100 W	
Deposition temperature	225 C	100 - 225 C
Bubbler temperature	65 C	



S.B.S. Heil, et al, *J. Vac. Sci. Technol. A*, 2008.

II. Development of thermal ALD Ta_2O_5 recipe

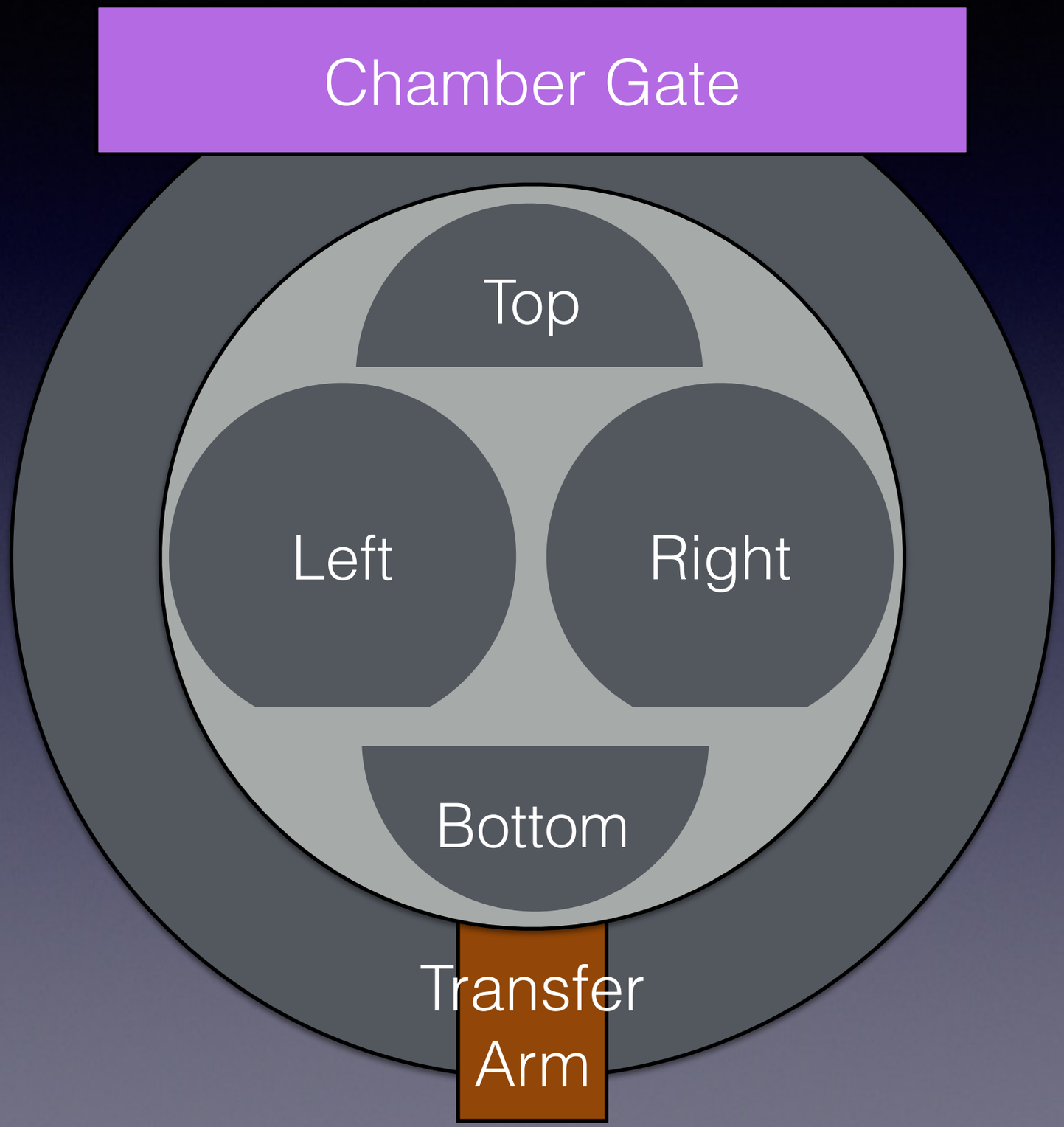
Thermal ALD control parameters

Constant	
Parameters	Values
Ar carrier gas flow	20 sccm/60 sccm
Ar plasma gas flow	40 sccm/200 sccm
Precursor temperature	75C/105C
APC	14 %/100 %
Turbo pump speed	> 48 kRPM
Precursor input lines/ manifold temperature	150 C

Thermal ALD control parameters

Constant		**Variable**	
Parameters	Values	Parameters	Values
Ar carrier gas flow	20 sccm/60 sccm	Process temperature	150 - 300 C
Ar plasma gas flow	40 sccm/200 sccm	Precursor dose time	0.6 - 3.6 sec
Precursor temperature	75C/105C	Precursor purge time	10 - 130 sec
APC	14 %/100 %	Water dose time	0.06 - 1 sec
Turbo pump speed	> 48 kRPM	Water purge time	10 - 120 sec
Precursor input lines/ manifold temperature	150 C	# of cycles	50 - 200 cycles

Thermal ALD control parameters



Finding thermal ALD Ta_2O_5 process parameters

Steps	Control variables
A. Find a baseline recipe w/ max. purge time	a. Process temperature b. Precursor/water purge time c. # of cycles

Step A: Finding a baseline recipe

Test #	Process Temp. [C]	Purge Time [s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL5	200	20	0.22	21.7	23	16.3	28.4	21.9	100
PL6	200	40	0.42	22.2	20.2	11.7	26.8	19.8	100
TH2	150	40	0.21	24.1	18.7	9.43	14.1	18.2	100
TH3	150	100	0.39	22	23.9	10.6	22.4	19.8	100
TH4	175	100	0.57	4.79	2.48	2.47	20.4	8.84	50
TH5	200	100	0.54	3.47	3.79	6.49	16.4	7.76	50
PL7	200	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)

Nonuni. Indicator
< 5 %
5 - 7 %
7 - 10 %
> 10 %

Finding thermal ALD Ta_2O_5 process parameters

Steps	Control variables
A. Find a baseline recipe w/ max. purge time	a. Process temperature b. Precursor/water purge time c. # of cycles
B. Find appropriate water dose/purge time	a. Water dose time b. Water purge time

Step B: Finding water dose/purge time

Test #	Water Dose Time[s]	Water Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	1	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH6	0.06	120	0.59	4.1	3.66	1.38	8.43	4.99	50 (2700)
TH7	0.12	120	0.59	3.78	3.31	4.03	19.5	9.01	50 (2750)
TH8	0.06	120	0.51	1.79	2.28	1.09	2.04	1.87	50 (2850)
TH10	0.06	10	0.49	4	3.45	2.47	9.99	5.35	50 (2900)
TH11	0.06	20	0.51	6.36	2.42	3.06	8.81	5.55	50 (2950)
TH12	0.06	40	0.51	2.64	2.17	2.51	3.06	2.59	50 (3050)
TH17	0.06	30	0.47	8.72	9.04	2.76	17	9.91	50 (3450)

Step B: Finding water dose/purge time

Test #	Water Dose Time[s]	Water Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	1	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH6	0.06	120	0.59	4.1	3.66	1.38	8.43	4.99	50 (2700)
TH7	0.12	120	0.59	3.78	3.31	4.03	19.5	9.01	50 (2750)
TH8	0.06	120	0.51	1.79	2.28	1.09	2.04	1.87	50 (2850)
TH10	0.06	10	0.49	4	3.45	2.47	9.99	5.35	50 (2900)
TH11	0.06	20	0.51	6.36	2.42	3.06	8.81	5.55	50 (2950)
TH12	0.06	40	0.51	2.64	2.17	2.51	3.06	2.59	50 (3050)
TH17	0.06	30	0.47	8.72	9.04	2.76	17	9.91	50 (3450)

Step B: Finding water dose/purge time

Test #	Water Dose Time[s]	Water Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	1	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH6	0.06	120	0.59	4.1	3.66	1.38	8.43	4.99	50 (2700)
TH7	0.12	120	0.59	3.78	3.31	4.03	19.5	9.01	50 (2750)
TH8	0.06	120	0.51	1.79	2.28	1.09	2.04	1.87	50 (2850)
TH10	0.06	10	0.49	4	3.45	2.47	9.99	5.35	50 (2900)
TH11	0.06	20	0.51	6.36	2.42	3.06	8.81	5.55	50 (2950)
TH12	0.06	40	0.51	2.64	2.17	2.51	3.06	2.59	50 (3050)
TH17	0.06	30	0.47	8.72	9.04	2.76	17	9.91	50 (3450)

Step B: Finding water dose/purge time

Test #	Water Dose Time[s]	Water Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	1	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH6	0.06	120	0.59	4.1	3.66	1.38	8.43	4.99	50 (2700)
TH7	0.12	120	0.59	3.78	3.31	4.03	19.5	9.01	50 (2750)
TH8	0.06	120	0.51	1.79	2.28	1.09	2.04	1.87	50 (2850)
TH10	0.06	10	0.49	4	3.45	2.47	9.99	5.35	50 (2900)
TH11	0.06	20	0.51	6.36	2.42	3.06	8.81	5.55	50 (2950)
TH12	0.06	40	0.51	2.64	2.17	2.51	3.06	2.59	50 (3050)
TH17	0.06	30	0.47	8.72	9.04	2.76	17	9.91	50 (3450)

Finding thermal ALD Ta_2O_5 process parameters

Steps	Control variables
A. Find a baseline recipe w/ max. purge time	a. Process temperature b. Precursor/water purge time c. # of cycles
B. Find appropriate water dose/purge time	a. Water dose time b. Water purge time
C. Find appropriate precursor dose/purge time	a. Precursor dose time b. Precursor purge time

Step C: Finding precursor dose/purge time

Test #	Precur. Dose Time[s]	Precur. Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	0.6	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH12	0.6	120	0.51	2.64	2.17	2.51	3.06	2.59	50 (3050)
TH16	0.6	120	0.51	3.94	5.23	2.7	5.77	4.55	50 (3350)
TH18	0.6	80	0.43	12.4	10.9	5.54	17.6	11.8	50 (3500)
TH19	0.6	90	0.48	3.84	3.84	4.46	11.6	6.15	50 (3550)
TH20	0.6	100	0.45	10.9	9.22	3.72	13.2	9.38	50 (3650)
TH21	0.6	110	0.49	2.72	3.43	2.53	13.8	6.53	50 (3700)

Step C: Finding precursor dose/purge time

Test #	Precur. Dose Time[s]	Precur. Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	0.6	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH22	0.6	120	0.45	2.53	2.69	0.77	13.2	6.17	200 (3900)
TH23	0.6	120	0.47	5.17	4.05	3.27	19.9	9.1	50 (4000)

Step C: Finding precursor dose/purge time

Test #	Precur. Dose Time[s]	Precur. Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	0.6	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH22	0.6	120	0.45	2.53	2.69	0.77	13.2	6.17	200 (3900)
TH23	0.6	120	0.47	5.17	4.05	3.27	19.9	9.1	50 (4000)
TH24	Standard thermal ALD Al2O3, 50 cycles		0.91	1.4	2.06	1.25	3.05	2.07	
TH25	Standard thermal ALD HfO2, 50 cycles		1.07	1.27	1.09	1.94	1.43	1.46	

Step C: Finding precursor dose/purge time

Test #	Precur. Dose Time[s]	Precur. Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	0.6	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH22	0.6	120	0.45	2.53	2.69	0.77	13.2	6.17	200 (3900)
TH23	0.6	120	0.47	5.17	4.05	3.27	19.9	9.1	50 (4000)
TH24	Standard thermal ALD Al2O3, 50 cycles		0.91	1.4	2.06	1.25	3.05	2.07	
TH25	Standard thermal ALD HfO2, 50 cycles		1.07	1.27	1.09	1.94	1.43	1.46	
TH15	0.6	80 @ 110 C	0.53	2.18	2.09	1.89	1.85	2.01	50 (3300)

Step C: Finding precursor dose/purge time

Test #	Precur. Dose Time[s]	Precur. Purge Time[s]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
PL7	0.6	120	0.56	2.61	1.91	5.51	3.25	3.44	50 (2650)
TH22	0.6	120	0.45	2.53	2.69	0.77	13.2	6.17	200 (3900)
TH23	0.6	120	0.47	5.17	4.05	3.27	19.9	9.1	50 (4000)
TH24	Standard thermal ALD Al2O3, 50 cycles		0.91	1.4	2.06	1.25	3.05	2.07	
TH25	Standard thermal ALD HfO2, 50 cycles		1.07	1.27	1.09	1.94	1.43	1.46	
TH15	0.6	80 @ 110 C	0.53	2.18	2.09	1.89	1.85	2.01	50 (3300)
TH26	**0.9**	**120**	**0.55**	3.04	1.73	0.99	12.9	6.21	50 (4075)
TH27	**0.9**	**130**	**0.53**	3.57	3.51	3.13	9.65	5.42	50 (4150)
TH28	**0.9**	**130**	**0.51**	3.84	3.09	0.76	18.2	8.27	200 (4525)

Finding thermal ALD Ta_2O_5 process parameters

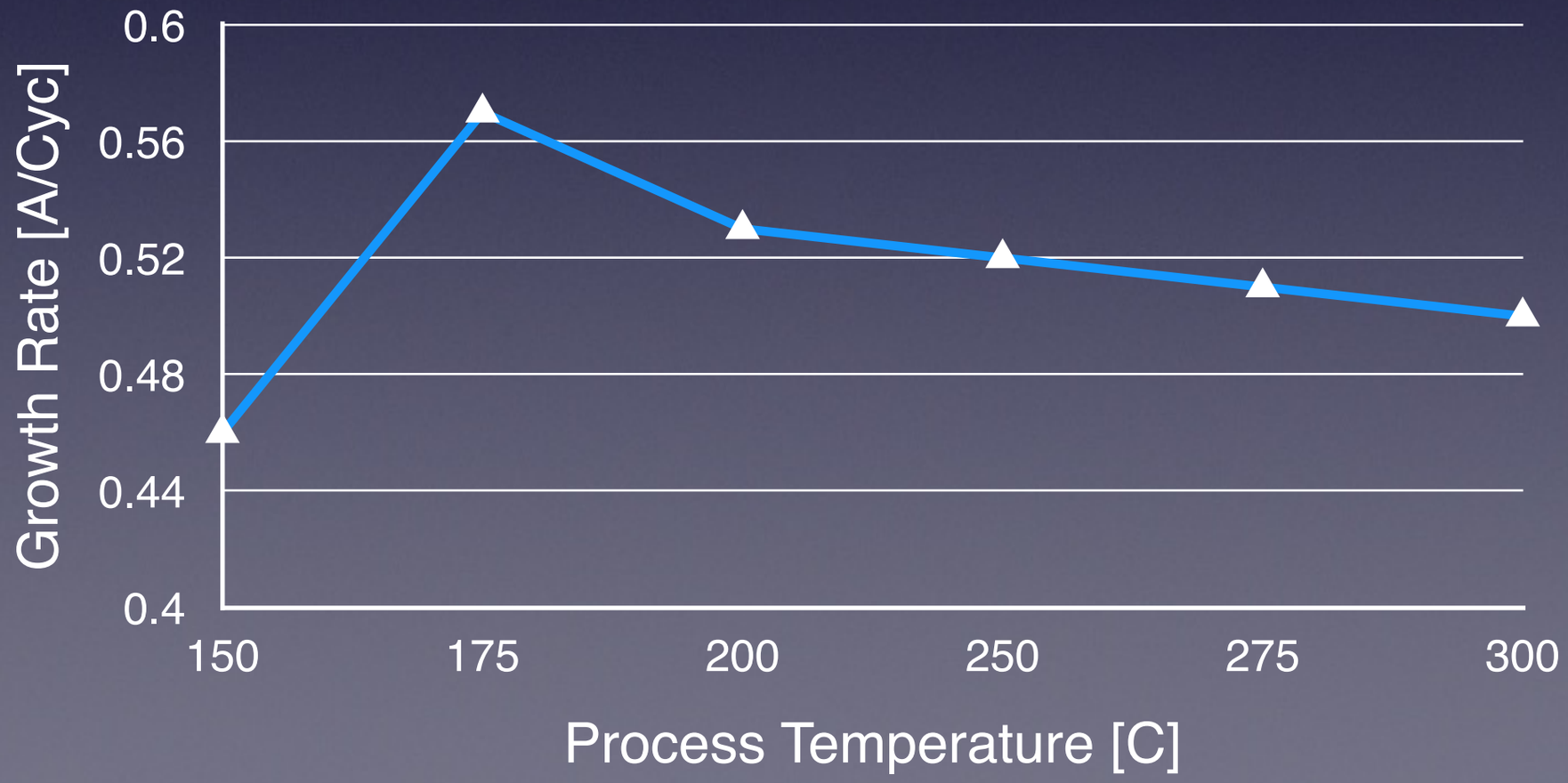
Steps	Control variables
A. Find a baseline recipe w/ max. purge time	a. Process temperature b. Precursor/water purge time c. # of cycles
B. Find appropriate water dose/purge time	a. Water dose time b. Water purge time
C. Find appropriate precursor dose/purge time	a. Precursor dose time b. Precursor purge time
D. Growth rate & process temperature relationship	Process temperature

Step D: Growth rate & process temperature

Test #	Process Temperature [C]	Growth Rate [A/cyc]	Nonuniformity Left/Right/Top/Bottom/Avg.					# of Cycles
TH27	200	0.53	3.57	3.51	3.13	9.65	5.42	50 (4150)
TH29	250	0.52	4.27	3.34	3.2	6.38	4.47	50 (4660)
TH30	275	0.51	3.84	3.86	2.18	7.67	4.74	50 (4735)
TH31	150	0.46	18.8	16.8	11.1	17.1	16.4	50 (4870)
TH32	175	0.57	7.75	6.58	2.18	18.3	9.67	50 (4945)
TH33	300	0.5	3.18	4.8	2.86	6.75	4.54	50 (5020)

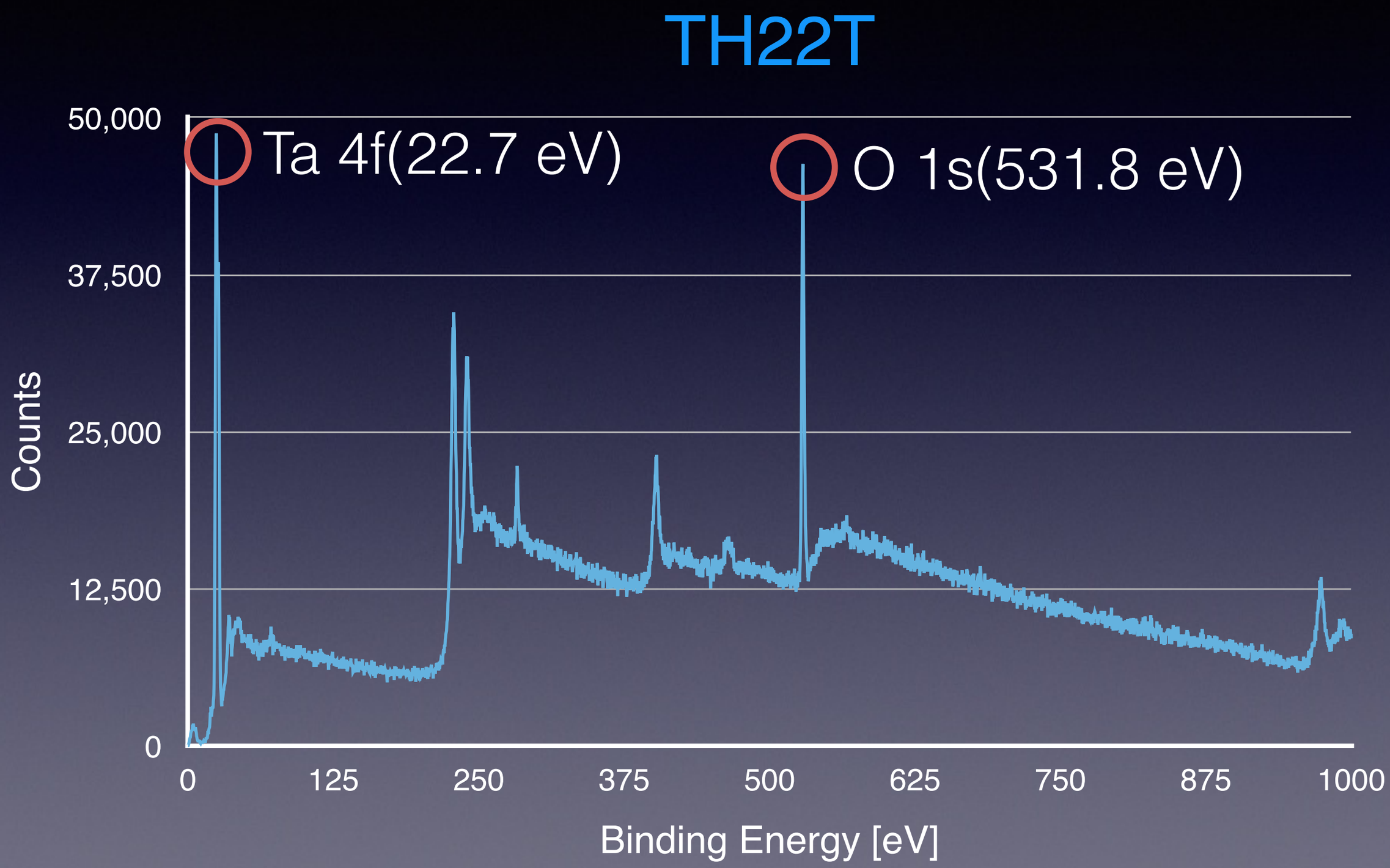
Step D: Growth rate & process temperature

Process Temperatur[C]	Growth Rate[A/Cyc]	Nonuniformit[%]
150	0.46	16.4
175	0.57	9.67
200	0.53	5.42
250	0.52	4.47
275	0.51	4.74
300	0.5	4.54

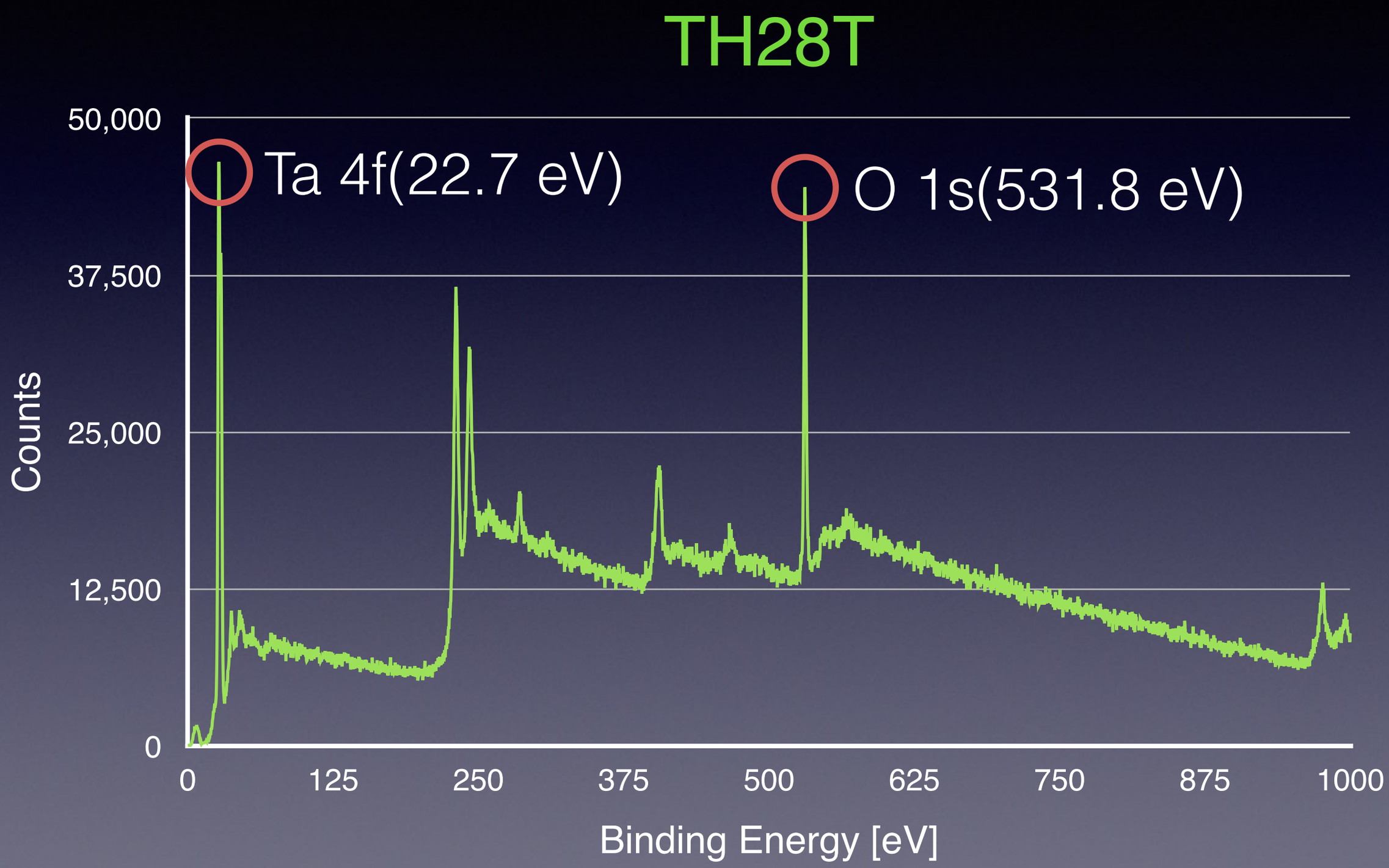


III. Characterization of thermal ALD Ta_2O_5 films

Stoichiometry of thermal ALD Ta_2O_5



Stoichiometry of thermal ALD Ta_2O_5



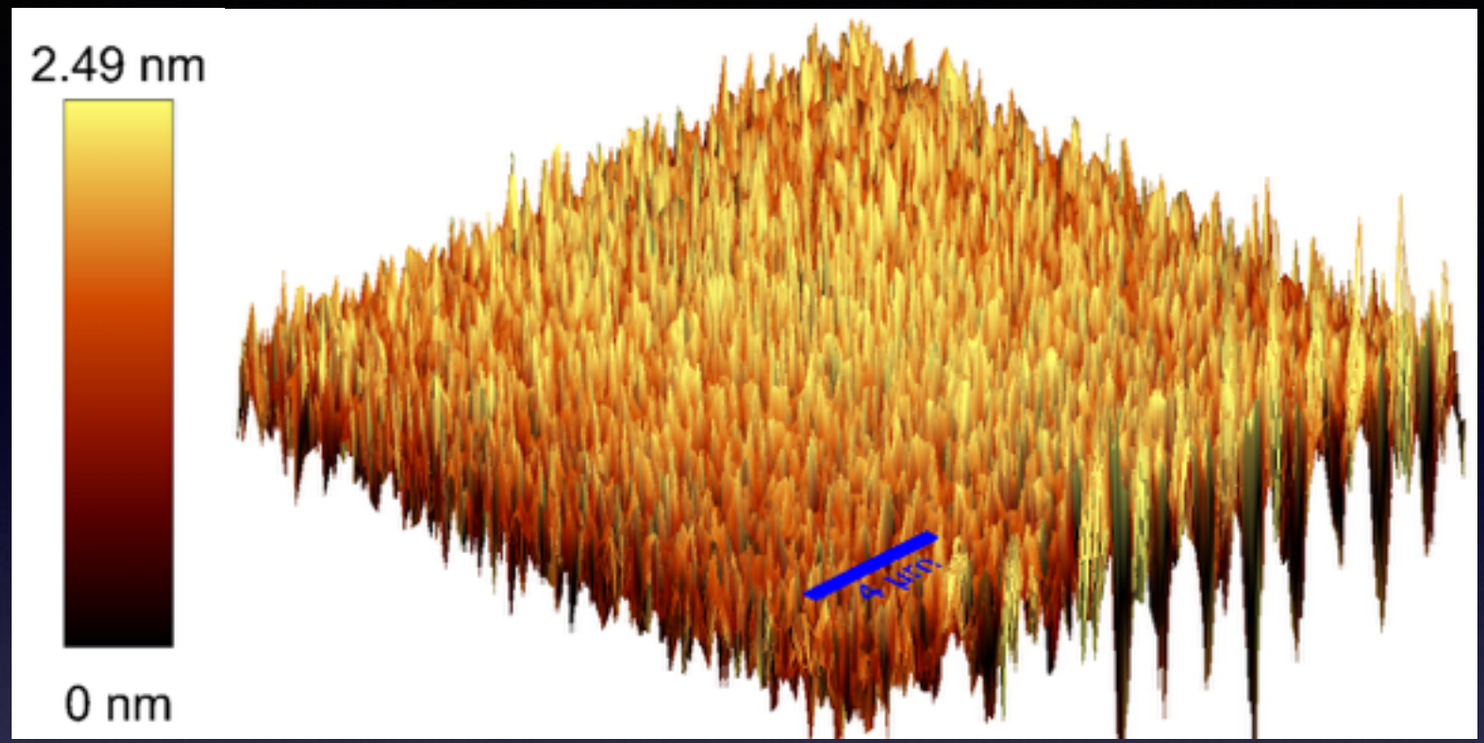
Stoichiometry of thermal ALD Ta_2O_5

Atomic Concentration Table

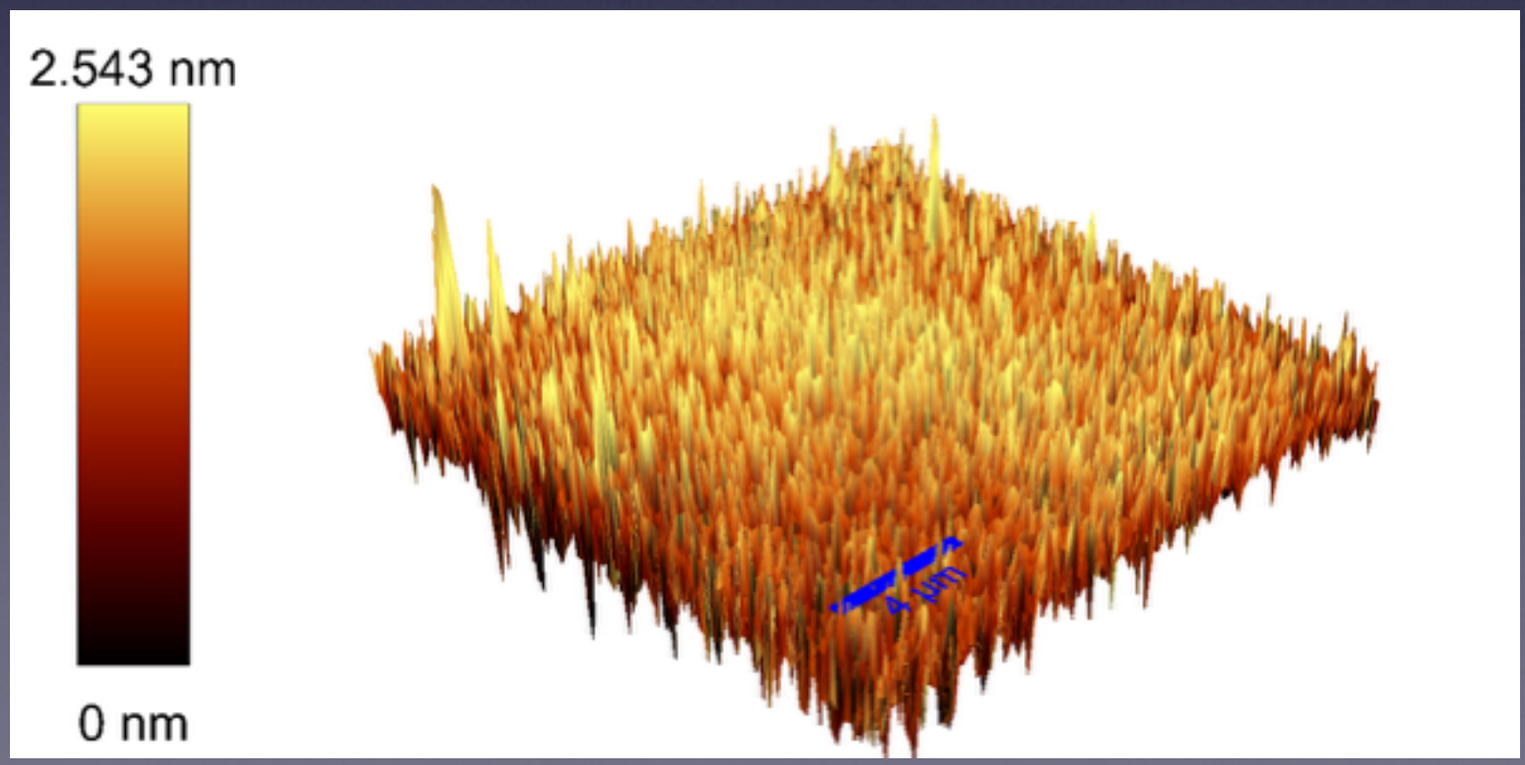
Sample #	Ta 4f	O 1s	Ta:O	Thickness [A]	Precursor Dose/Purge time [sec]
TH22T	23.35	57.00	2:4.88	92.9	0.6/120
TH28T	22.84	56.65	2:4.96	104	0.9/130

Surface roughness of thermal ALD Ta_2O_5

TH22T



TH28T



IV. Future works

Future Works

Goals	Tasks
A. Recheck deposition conditions of thermal ALD Ta	Check precursor dose/purge time
B. Find a standard recipe of PEALD Ta	Find other control parameters(i.e. O flow rate, O power, Plasma exposure time)
C. Crystal structure analysis of thermal/PE-ALD Ta	Observe crystal structure of thermal/ PE-ALD Ta
D. Conduct electrochemical corrosion tests	Compare corrosion effectiveness of thermal ALD/PEALD Ta

Thank you

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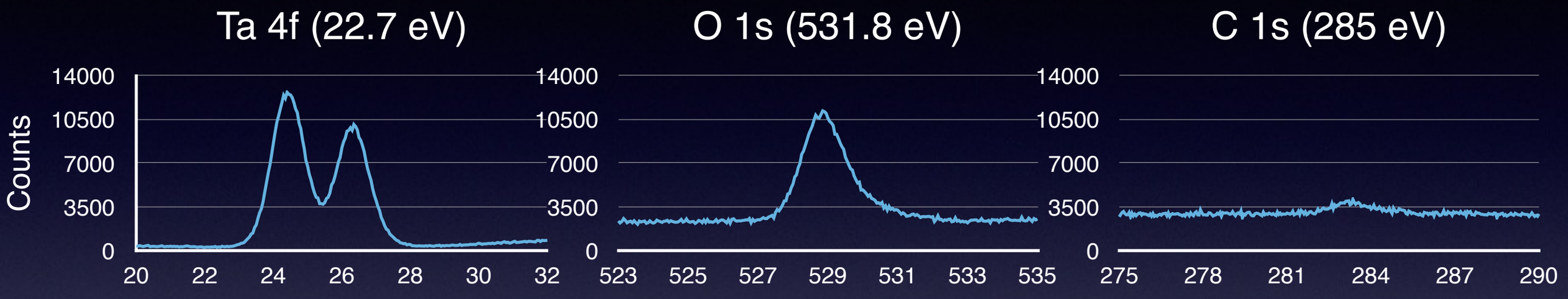
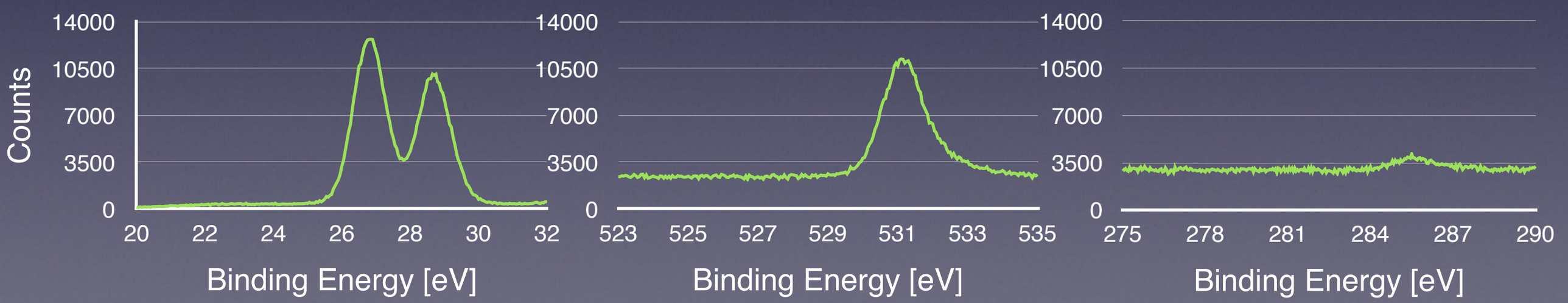
ANY
QUESTIONS
?

Stoichiometry of thermal ALD Ta_2O_5

TH22T



TH28T



Stoichiometry of thermal ALD Ta_2O_5

Atomic Concentration Table

Sample #	Ta 4f	O 1s	Ta:O	C 1s	Thickness [A]	Precursor Dose/ Purge time [sec]
TH22T	23.35	57.00	2:4.88	19.65	92.9	0.6/120
TH28T	22.84	56.65	2:4.96	20.51	104	0.9/130