NNCI ETCH WORKSHOP
Cornell University
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HBr Etching of Silicon

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Characteristics of HBr based etching of Silicon

- HBr plasmas tend to be somewhat electronegative in nature.
- Ionization is a function of electron density, electron temperature, ionization cross section, etc.
- Neutral composition depends on recombination rates and sticking coefficients. Br has a high recombination rate and where it happens matters.
- Density of Br radicals is highest in a seasoned chamber where recombination is minimized.
- Seasoned chambers have a stable coating of SiOBr inhibiting recombination.
- Stable seasoned chamber conditions lead to reproducible etch results.
- Chamber conditions directly influence plasma neutral and ion composition.

Characteristics of HBr etching of Silicon

- Amorphous reactive etch layer (REL) of a few nm forms by breaking Si-Si bonds inducing formation of Si bonded to Br, H, and O.
- SiBr4 formation is not spontaneous but requires an ion energy threshold of 10eV in HBr plasmas.
- In pure Br2 plasmas, a threshold energy of 44eV is needed to form SiBr4.
- SiH2Br2 is more volatile than SiBr4 due to the presence of H.
- Ion bombardment activates the Si surface allowing H to enter the Si lattice, breaking Si-Si bonds, allowing adsorbed Br atoms to reach activated sites.
- Si-O bond is stronger than Si-Br bond and is thermodynamically favored so as to decrease the etch rate by increasing the REL thickness.
- Ions supply the required activation energy to break Si-Si bonds to enable the formation of volatile products→ ion enhanced chemical sputtering mechanism.

Comparison between Cl2 and HBr based Si RIE

- Both Cl and Br have high recombination rates.
- Both form stable seasoned chamber coatings of SiOCl and SiOBr.
- Reproducible etch rates are very dependent on stable chamber conditions.
- Surface adsorption coverage of Cl on silicon is 1.6X higher than that of Br.
- Ion flux in HBr is 40% less than Cl2 due to a decreased ion density.
- Lower etch rates in HBr by 50% due to less adsorption and reduced ion flux.
- Fewer etch artifacts with HBr such as micro-trenching and faceting.
- Resist selectivities are somewhat higher with HBr than Cl2.
- Differences in sidewall protection layers of SiOBr and SiOCl responsible for different etch profile evolutions and artifacts.
- Ion bombardment angle induced etch yields are different with HBr having a wider angle distribution leading to less scattering and fewer artifacts.
- HBr has a narrower ion energy distribution due to similar masses of the principal ions of HBr+ and Br+ leading to less pronounced trenching.

Oxford Cobra ICP
HBr Si etch with PR mask DOE

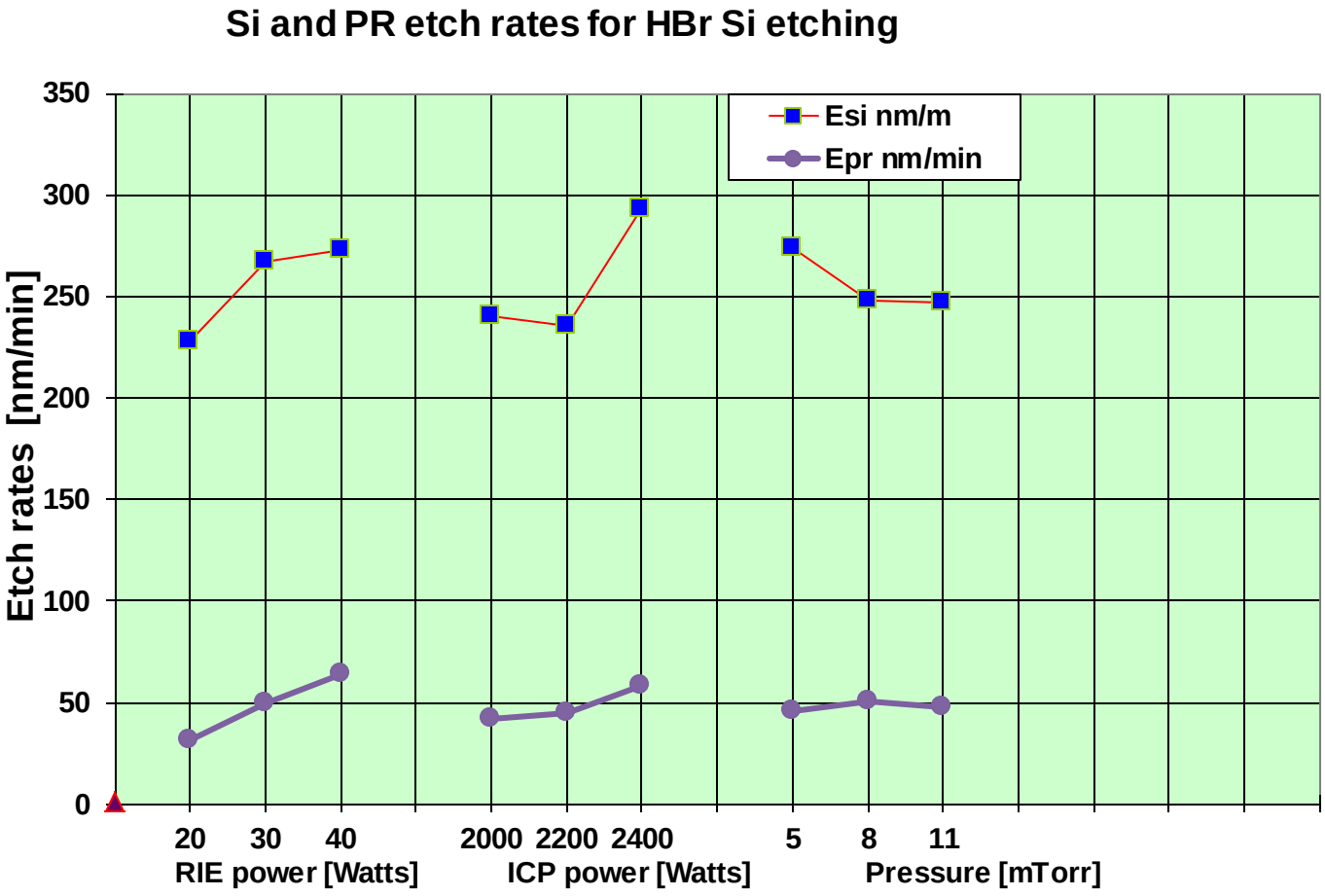
MATRIX EXPERIMENTS				
Run	RIE	ICP	Pre	Ar
1	20	2000	5	
2	20	2200	8	
3	20	2400	11	
4	30	2000	11	
5	30	2200	5	
6	30	2400	8	
7	40	2000	8	
8	40	2200	11	
9	40	2400	5	

L9 design				
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	3	2
5	2	2	1	3
6	2	3	2	1
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2

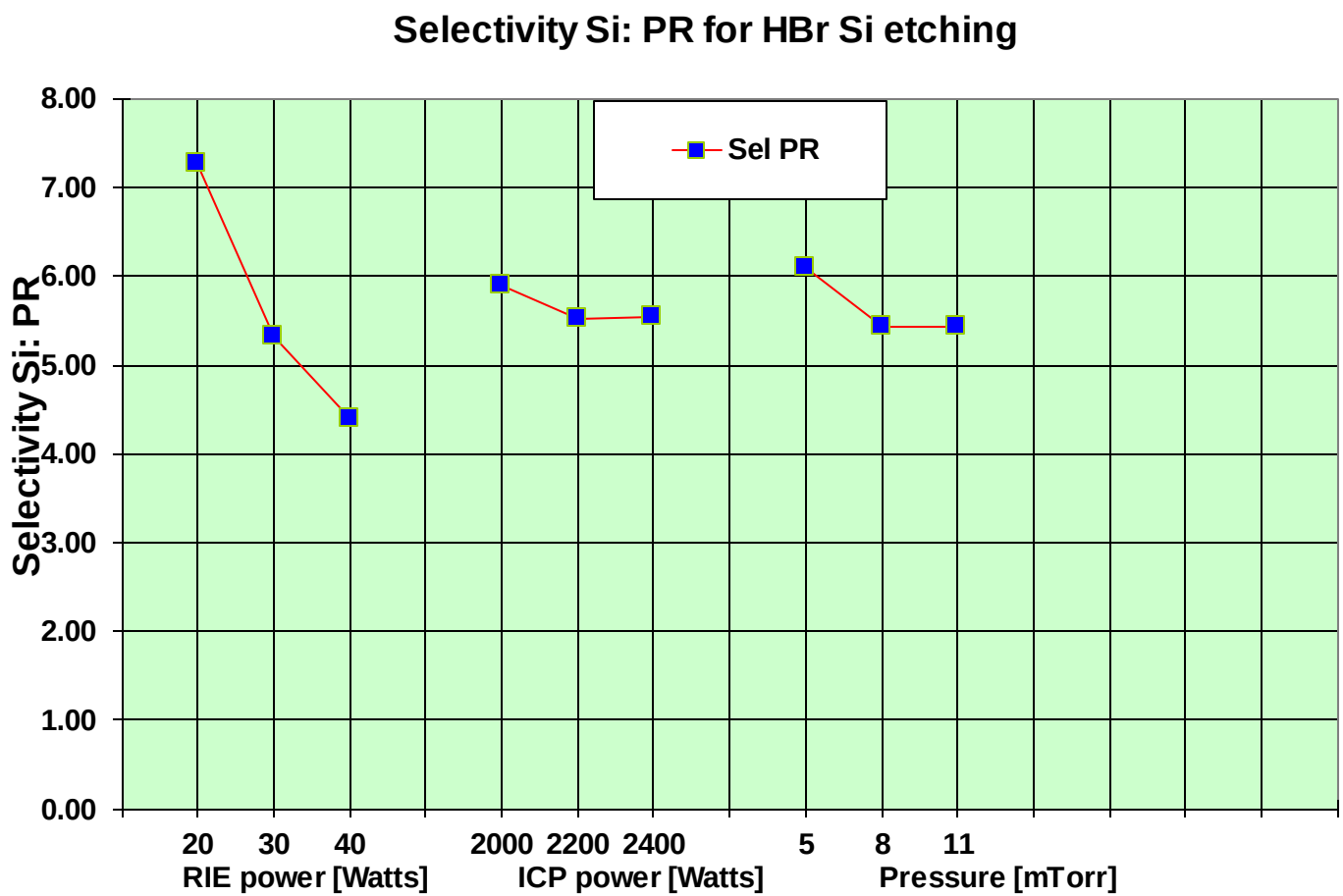
MEASURED RESULTS							
Run	Esi nm/m	Epr nm/min	Sel PR	DC [-V]	CONSTANT PARAMETERS		Profile
1	262	34	7.71	5	HBr	20sccm	trenching , bowing
2	233	32	7.28	9	Temperature	10degC	trenching
3	190	28	6.79	10	Backside He	10Torr	slight corner rounding
4	177	34	5.21	15	Etch time	8minutes	very slight trench
5	269	57	4.72	9			good
6	356	59	6.03	9			trenching
7	282	59	4.78	31			slight trench-good
8	204	45	4.53	49			pretty good
9	334	87	3.84	14			faceting

PARAMETER LEVEL AVERAGES (PLOTTED ON GRAPHS)					
Parameter	Level	Esi nm/m	Epr nm/min	Sel PR	DC [-V]
	20	228	31	7.26	8
RIE	30	267	50	5.32	11
	40	273	64	4.38	31
	2000	240	42	5.90	17
ICP	2200	235	45	5.51	22
	2400	293	58	5.55	11
	5	274	46	6.09	21
Pre	8	248	51	5.44	13
	11	247	48	5.43	17

Oxford Cobra ICP
HBr Si etch with PR mask

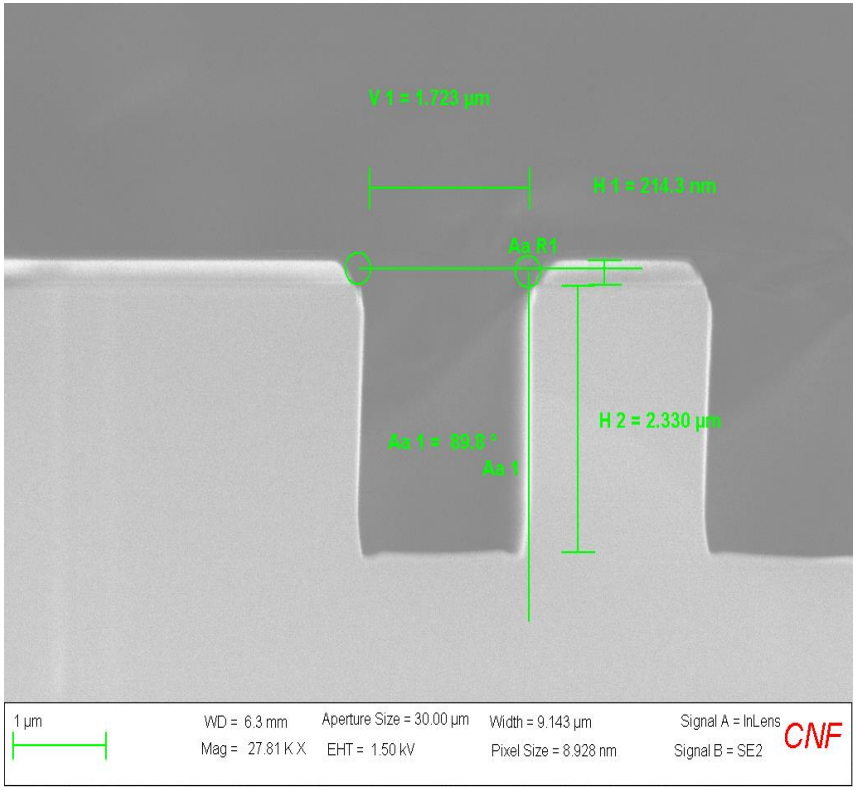


Oxford Cobra ICP
HBr Si etch with PR mask

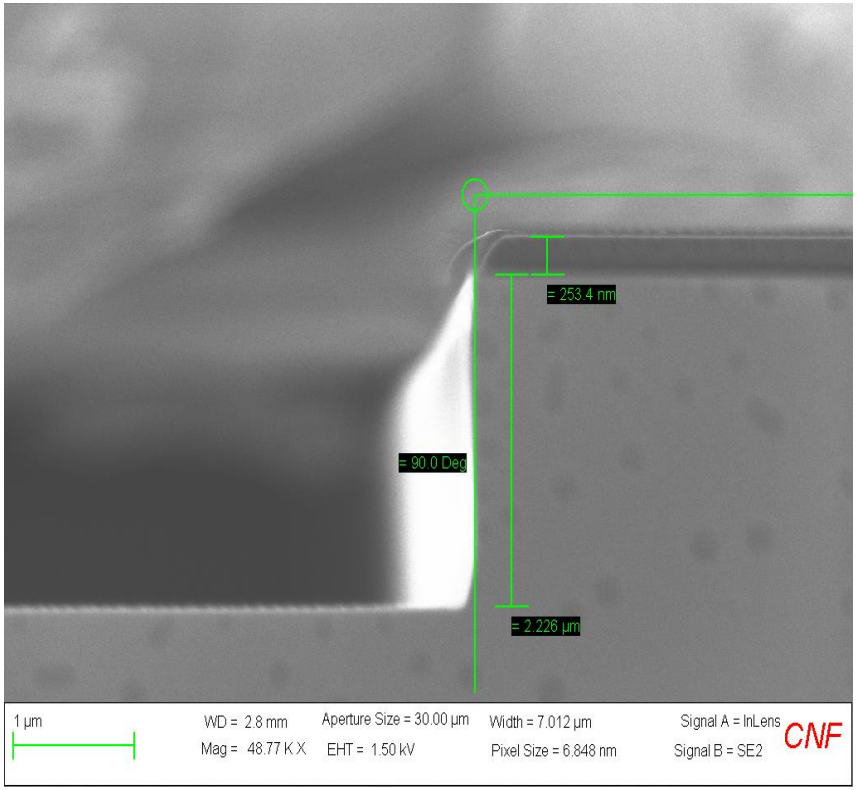


Oxford Cobra ICP
HBr Si etch with PR mask

HBr=20, ICP/RIE=2000W/40W, 8mtorr
ER=282nm/min, SPR=4.8:1

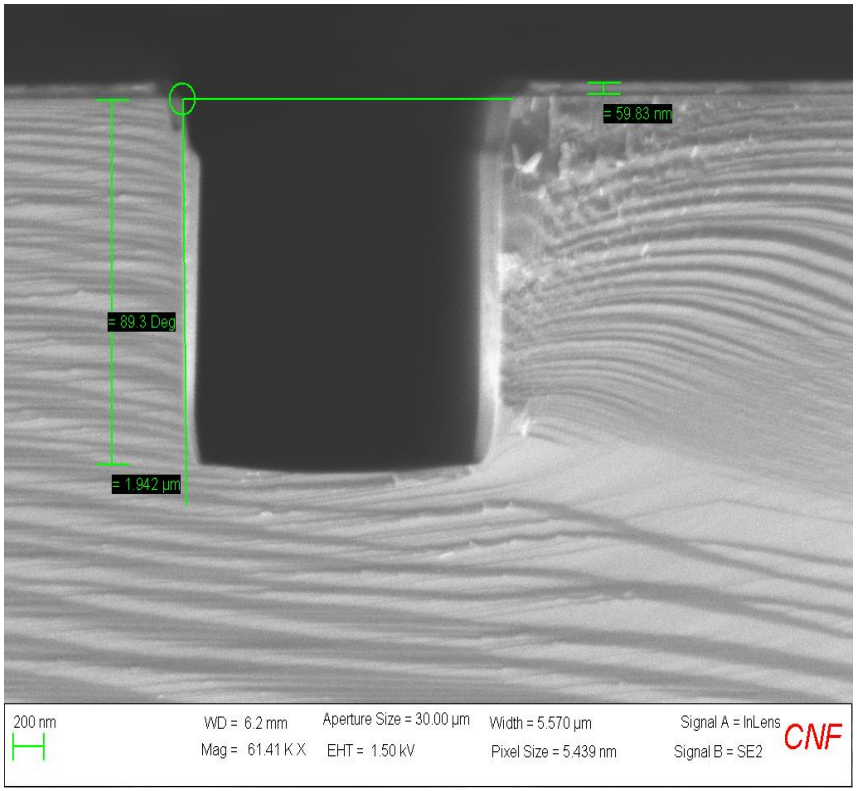


HBr=20, ICP/RIE=2200W/30W, 5mtorr
ER=269nm/min, SPR=4.7:1

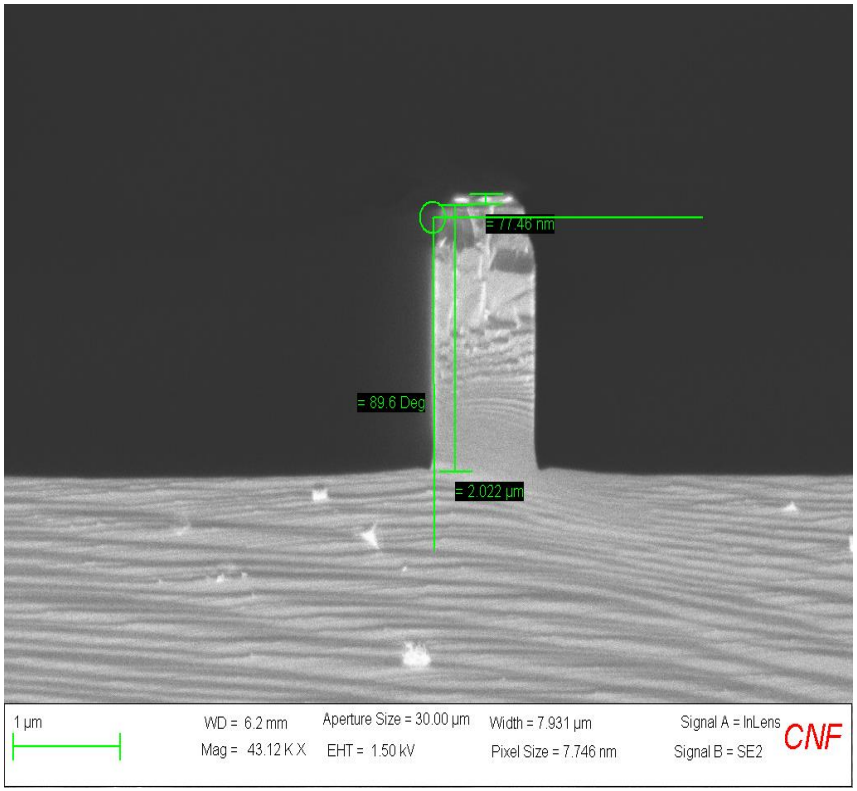


Oxford Cobra ICP
HBr Si etch DOE with PR mask

HBr=20, ICP/RIE=2000W/40W, 8mtorr



HBr=20, ICP/RIE=2000W/40W, 8mtorr



Oxford Cobra ICP
HBr/Ar Si etch with PR mask DOE

MATRIX EXPERIMENTS

Run	RIE	ICP	Pre	Ar
1	20	1500	5	4
2	20	1700	8	7
3	20	1900	11	10
4	30	1500	11	7
5	30	1700	5	10
6	30	1900	8	4
7	40	1500	8	10
8	40	1700	11	4
9	40	1900	8	7

L9 design			
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

MEASURED RESULTS

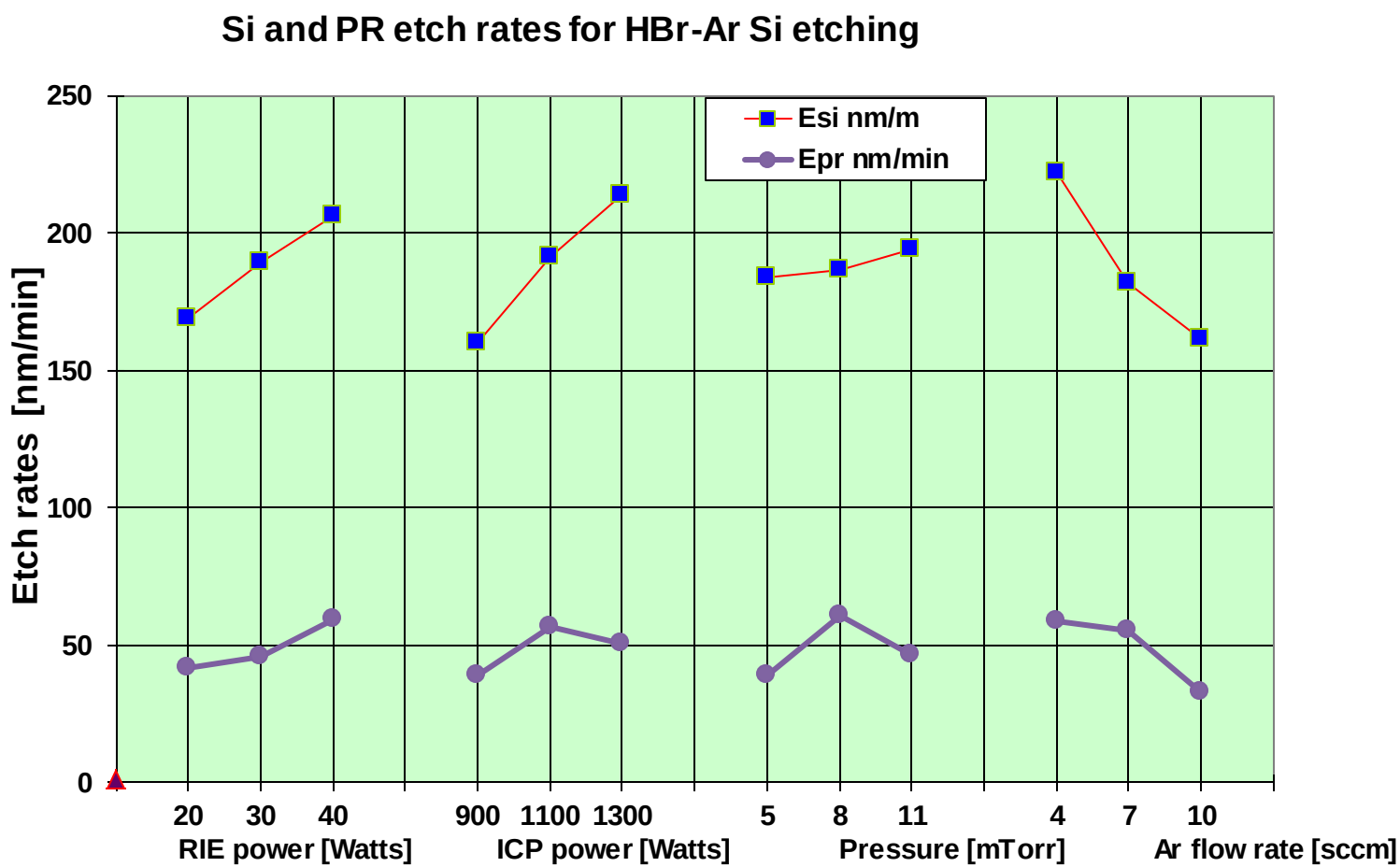
Run	Esi nm/m	Epr nm/min	Sel PR	DC [-V]	Profile [°]	Comments
1	171	32	5.34	20	90.0	very slight
2	164	68	2.41	24	87.0	trenching
3	173	25	6.92	28	90.0	trenching
4	133	32	4.16	53	92.0	good
5	232	61	3.80	30	88.0	slightly rou
6	204	44	4.64	44	90.0	slight facet
7	177	54	3.28	58	90.0	good
8	178	41	4.34	80	90.0	good
9	264	83	3.18	40	90.0	faceting

Constant parameters	
HBr	20sccm
Temperature	10degC
Backside He	10Torr
Etch time	8minutes

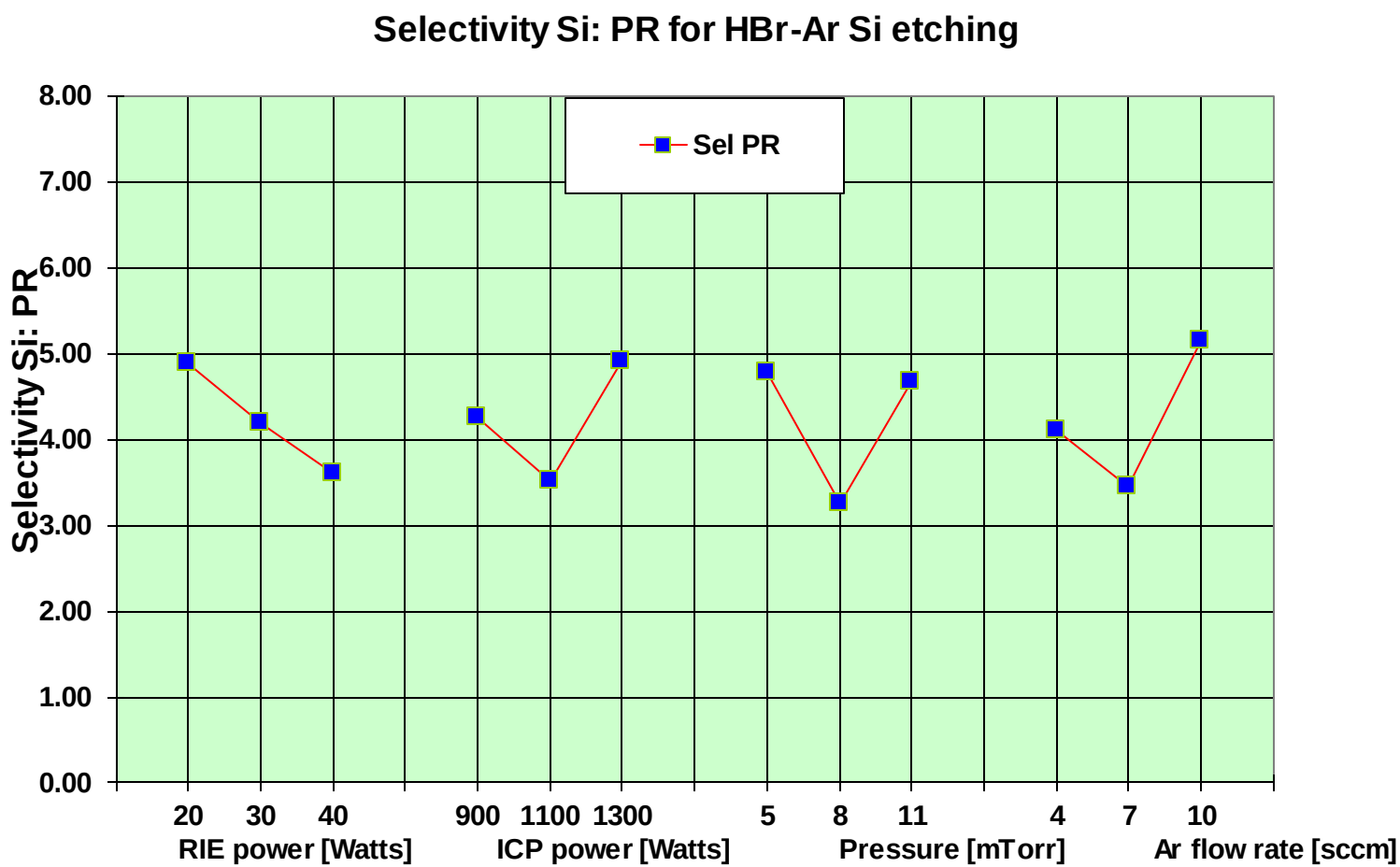
PARAMETER LEVEL AVERAGES (PLOTTED ON GRAPHS)

Parameter	Level	Esi nm/m	Epr nm/min	Sel PR	DC [-V]	Profile [°]
	20	169	42	4.89	24	89.0
RIE	30	190	46	4.20	42	90.0
	40	206	59	3.60	59	90.0
	900	160	39	4.26	44	90.7
ICP	1100	191	57	3.52	45	88.3
	1300	214	51	4.91	37	90.0
	5	184	39	4.77	48	90.0
Pre	8	187	61	3.25	39	89.7
	11	194	47	4.67	39	89.3
	4	222	59	4.11	30	89.3
Ar	7	182	55	3.44	42	89.0
	10	161	33	5.14	54	90.7

Oxford Cobra ICP
HBr/Ar Si etch DOE with PR mask

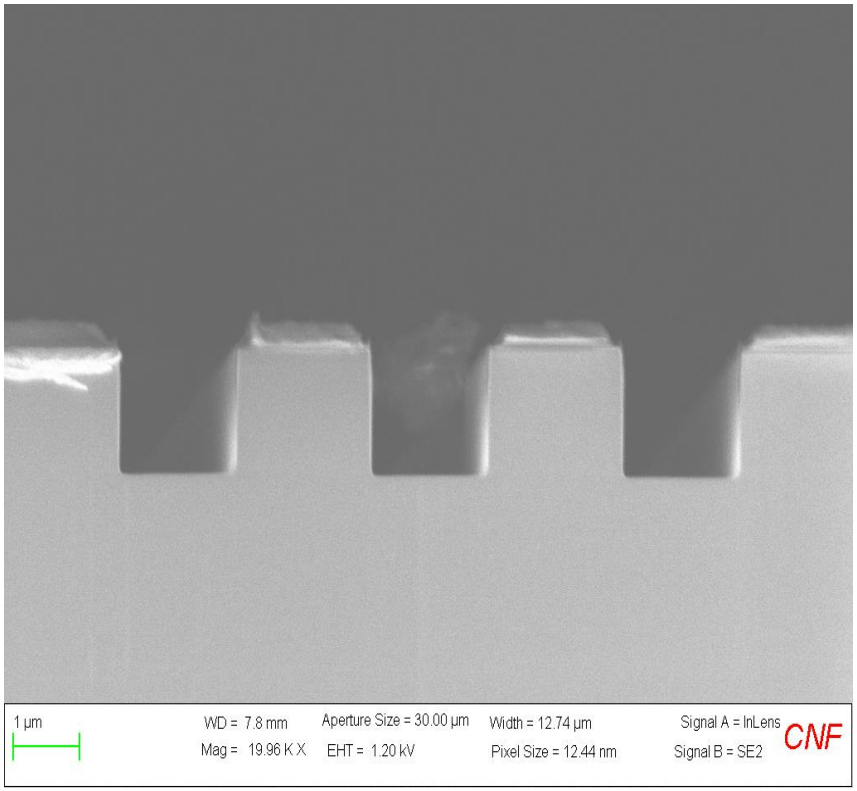


Oxford Cobra ICP
HBr/Ar Si etch DOE with PR mask

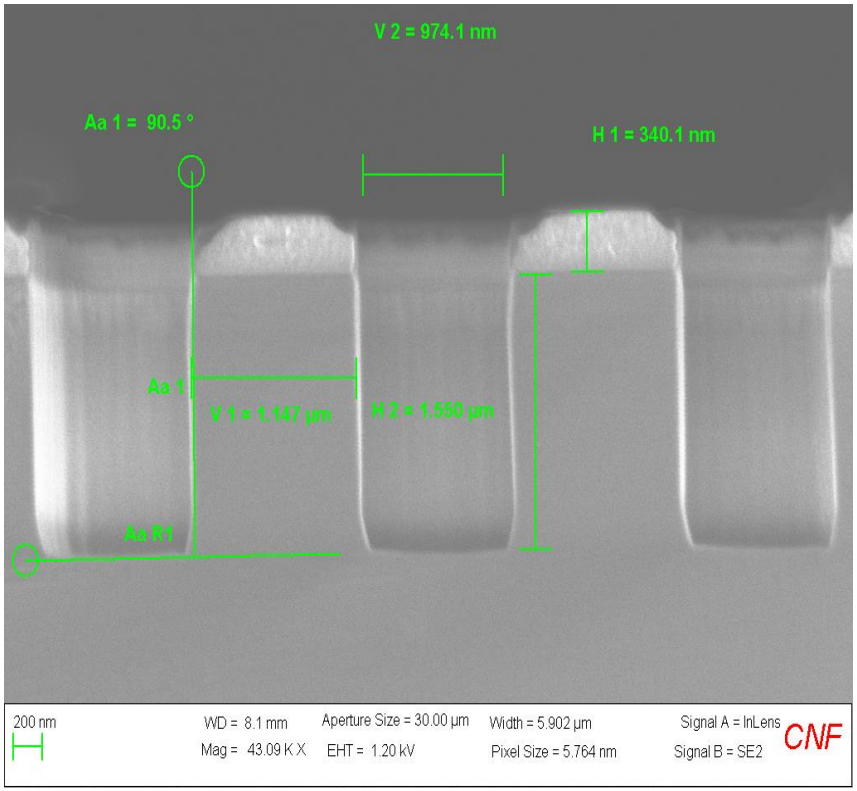


Oxford Cobra ICP
HBr/Ar Si etch DOE with PR mask

HBr/Ar=20/10, ICP/RIE=1500W/40W, 8mtorr
ER=177nm/min, SPR=3.3:1

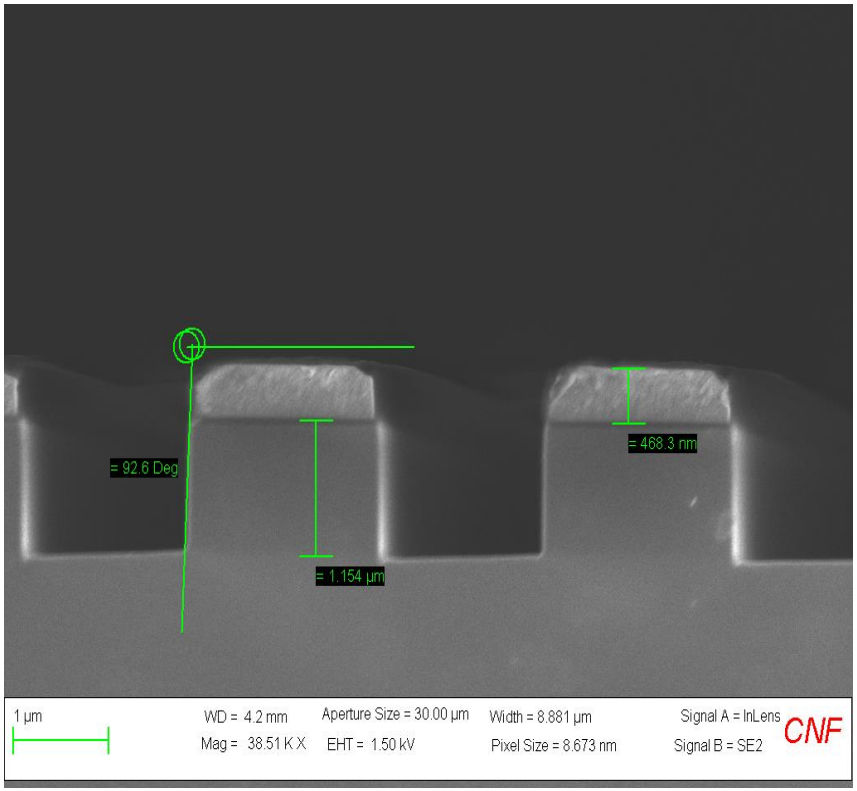


HBr/Ar=20/4, ICP/RIE=1900W/30W, 8mtorr
ER=204nm/min, SPR=4.6:1

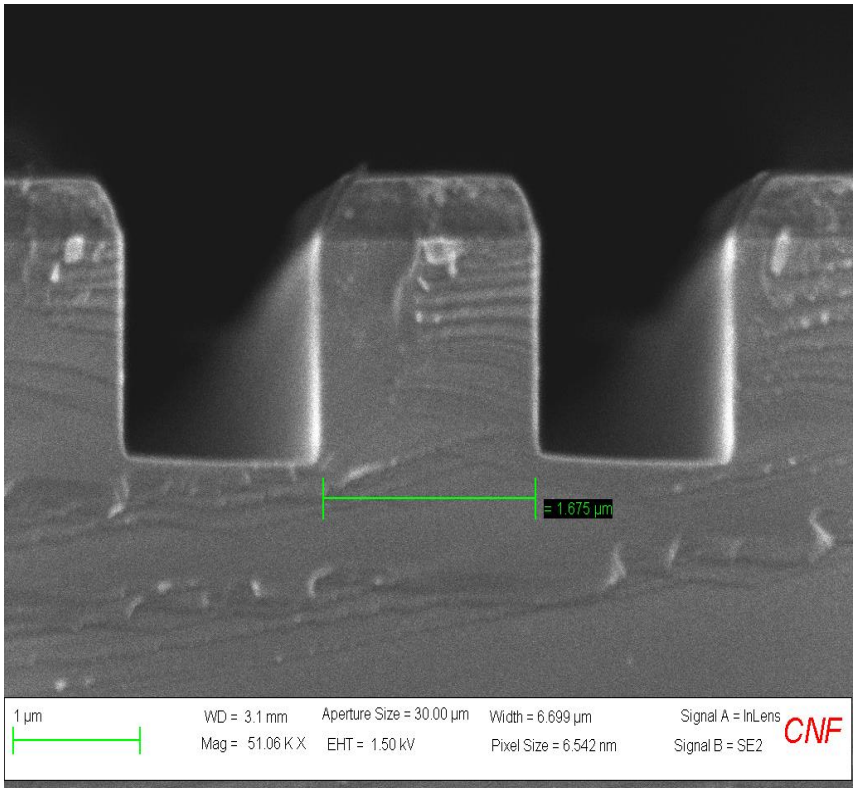


Oxford Cobra ICP
HBr/Ar Si etch DOE with PR mask

HBr/Ar=20/7, ICP/RIE=1500W/30W, 11mtorr
ER=133nm/min, SPR=4.2:1

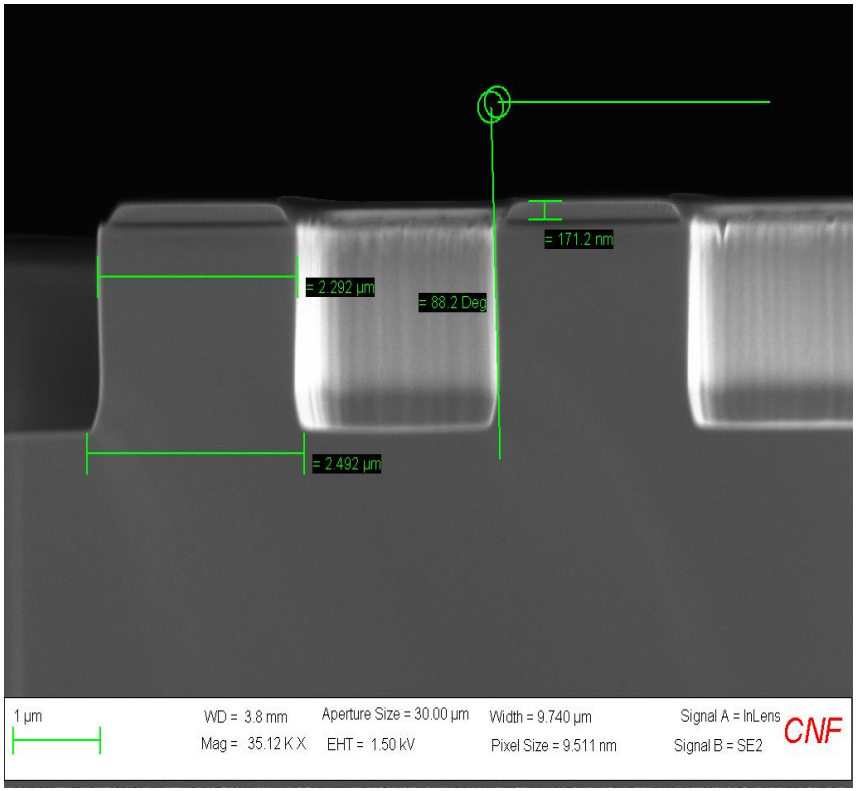


HBr/Ar=20/4, ICP/RIE=1700W/40W, 11mtorr
ER=178nm/min, SPR=4.3:1

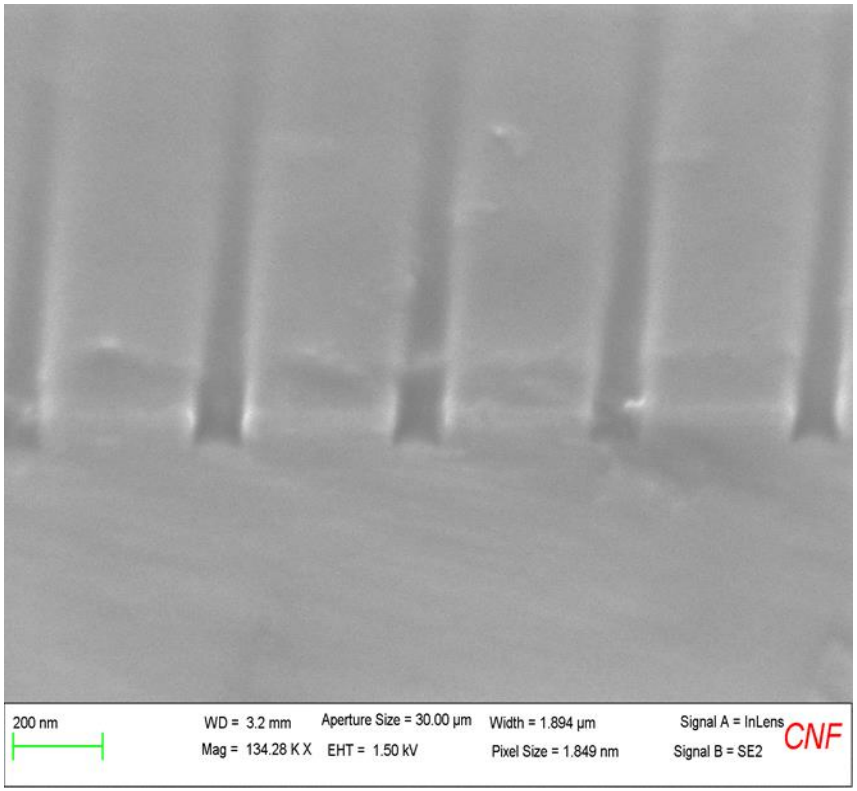


Oxford Cobra ICP
HBr/Ar Si etch DOE PR and ebeam resist mask

HBr/Ar=20/10, ICP/RIE=1700W/30W, 5mtorr
ER=232nm/min, SPR=3.8:1



HBr/Ar=20/7, ICP/RIE=1500W/30W, 11mtorr,
95nm/min, SZEP=3:1, 75nm gaps



Oxford Cobra ICP
HBr/Ar Si etch DOE with oxide mask

MATRIX EXPERIMENTS				
Run	RIE	ICP	Pre	Ar
1	20	1500	5	4
2	20	1700	8	7
3	20	1900	11	10
4	30	1500	11	7
5	30	1700	5	10
6	30	1900	8	4
7	40	1500	8	10
8	40	1700	11	4
9	40	1900	8	7

L9 design				
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	3	2
5	2	2	1	3
6	2	3	2	1
7	3	1	2	3
8	3	2	3	1
9	3	3	1	2

MEASURED RESULTS				
Run	Esi nm/m	EOX nm/min	Sel OX	DC [-V]
1	203	10	20.30	19
2	208	7	29.71	26
3	112	7	16.00	33
4	149	7	21.29	30
5	256	19	13.47	31
6	252	14	18.00	24
7	194	12	16.17	54
8	165	9	18.33	50
9	291	25	11.64	17

CONSTANT PARAMETERS	
HBr	20sccm
Temperature	10degC
Backside He	10Torr
Etch time	10 minutes

Breakthru step: BCl3/Ar=20/5, 25W/1000W, 10mT, 20 sec.

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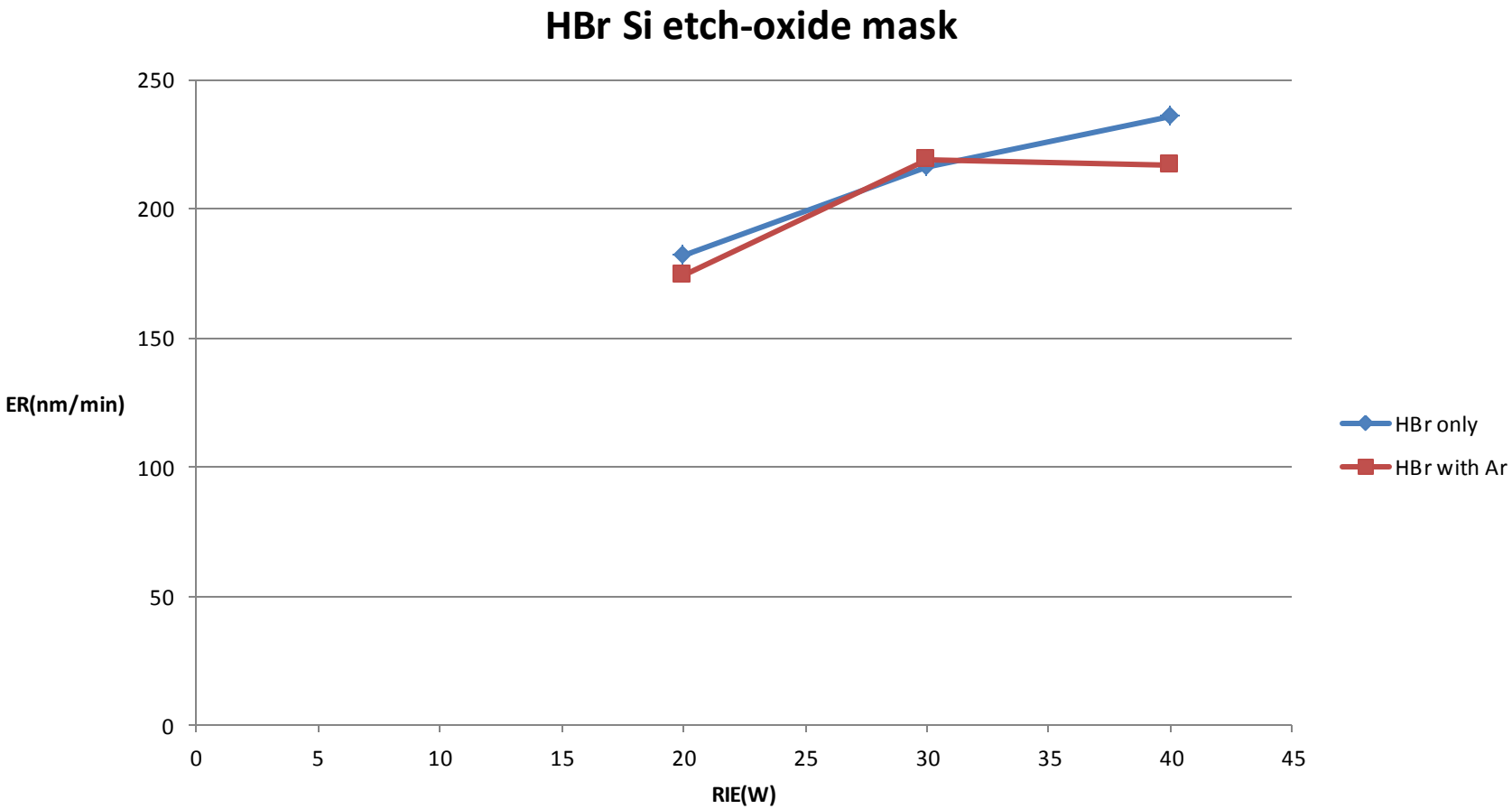
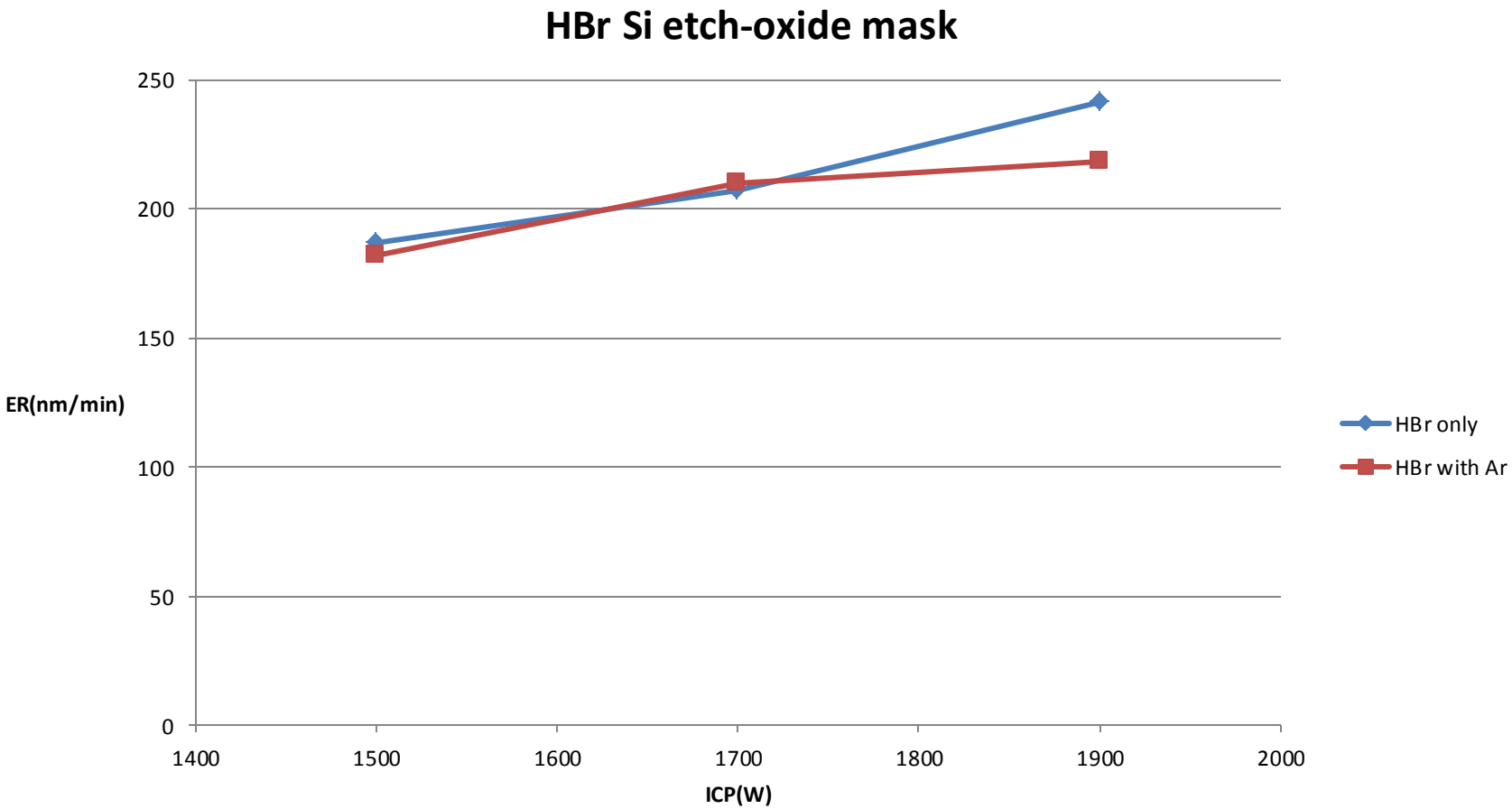
PARAMETER LEVEL AVERAGES (PLOTTED ON GRAPHS)					
Parameter	Level	Esi nm/m	EOX nm/min	Sel oxide	DC [-V]
	20	174	8	22.00	26
RIE	30	219	13	17.59	28
	40	217	15	15.38	40
	1500	182	10	19.25	34
ICP	1700	210	12	20.51	36
	1900	218	15	15.21	25
	5	207	11	18.88	31
Pre	8	216	13	20.88	24
	11	187	13	15.21	39
	4	250	18	15.14	22
Ar	7	218	11	21.29	35
	10	142	8	18.54	38

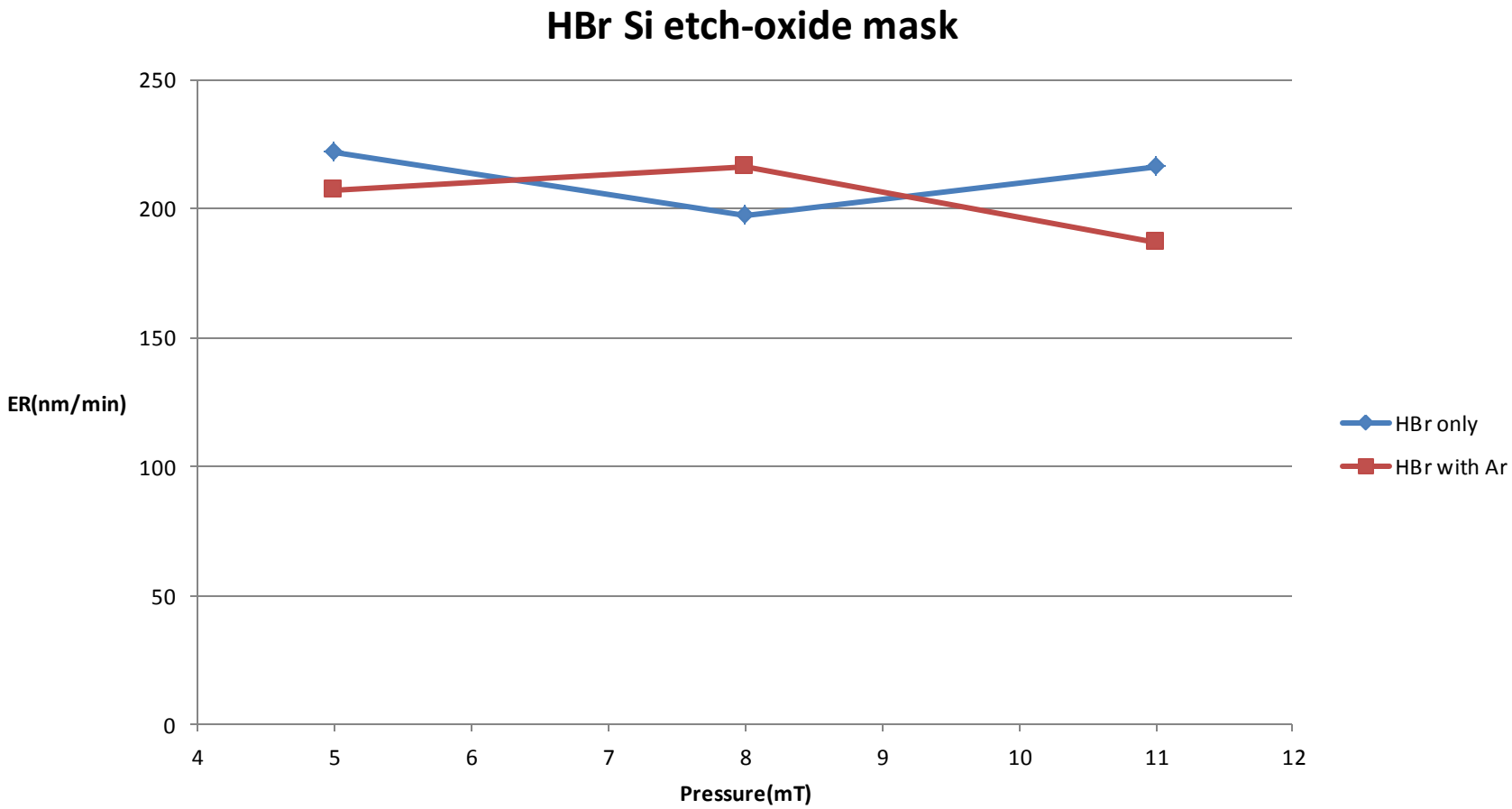
Oxford Cobra ICP
HBr/Ar vs.HBr Si etch DOE with oxide mask



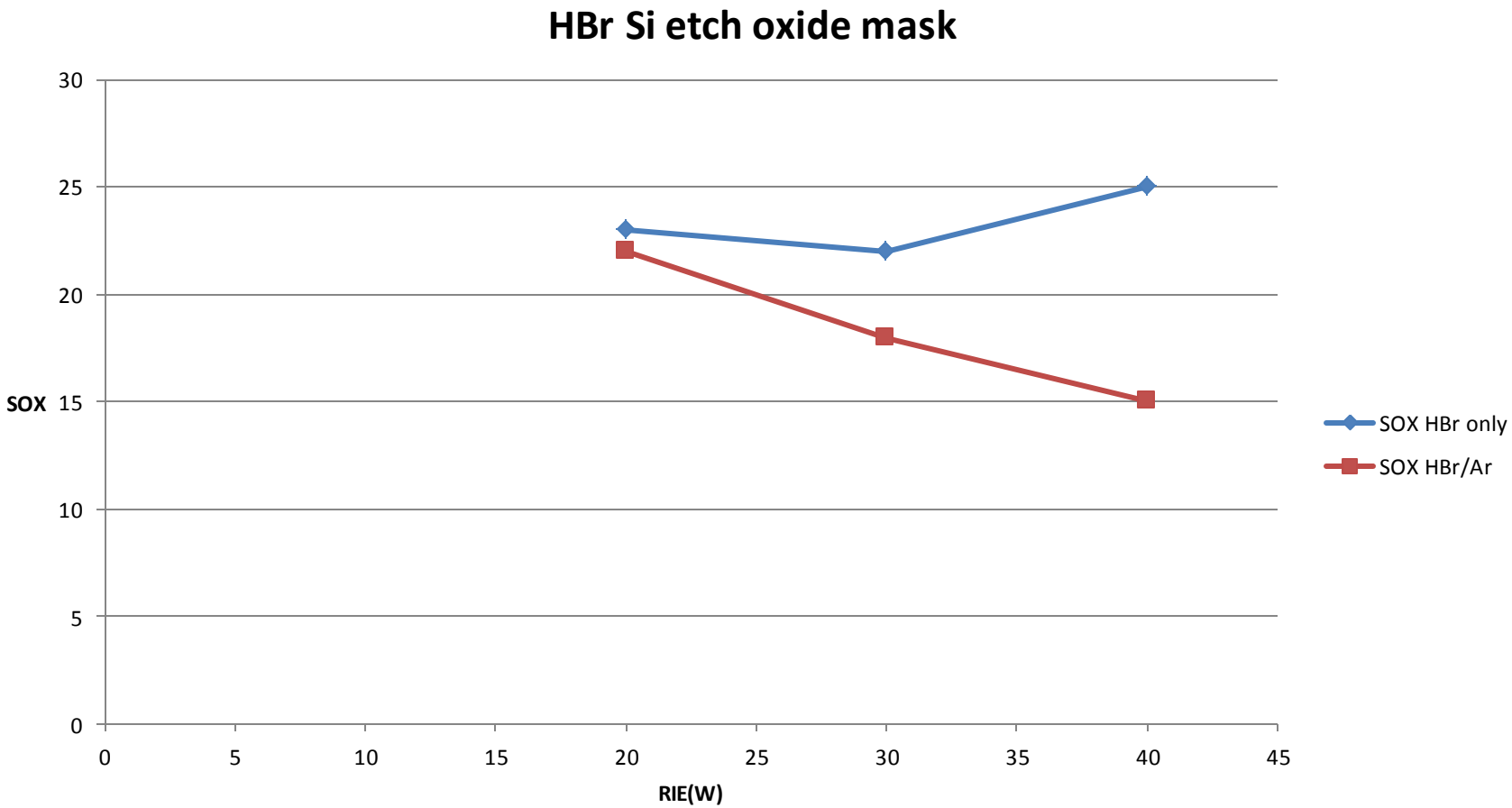
Oxford Cobra ICP
HBr/Ar vs. HBr Si etch DOE with oxide mask



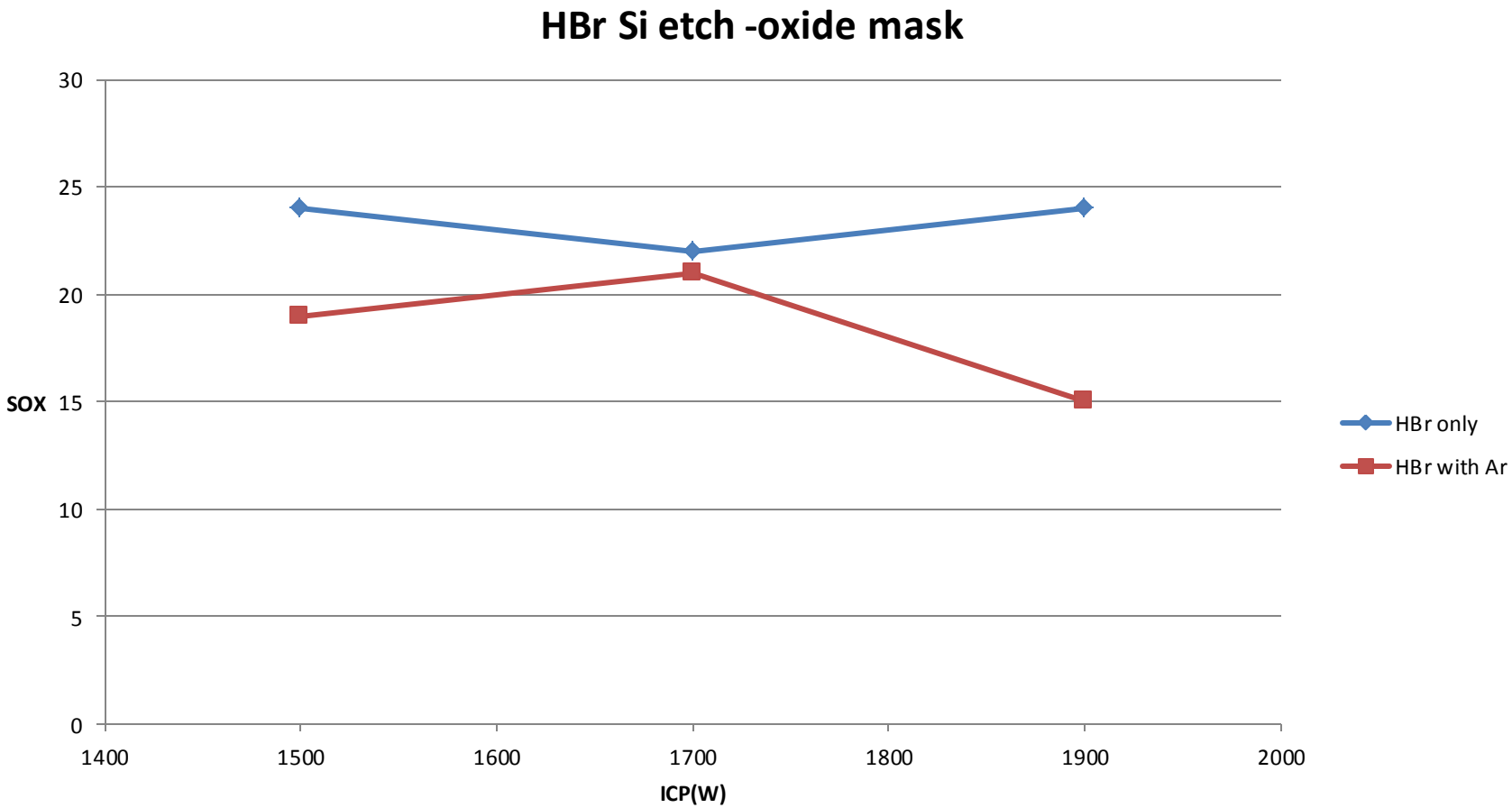
Oxford Cobra ICP
HBr/Ar vs. HBr Si etch DOE with oxide mask



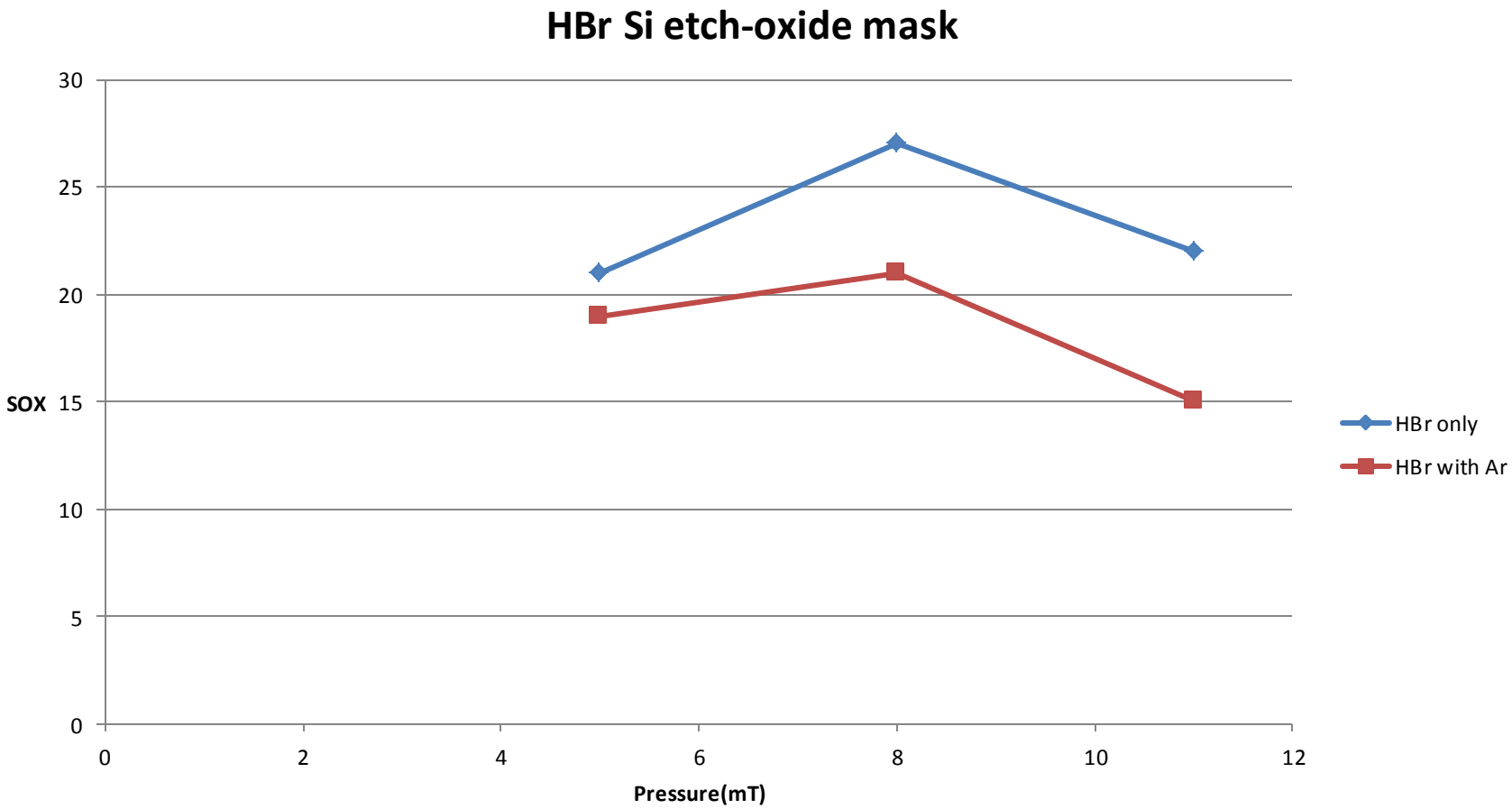
Oxford Cobra ICP
HBr/Ar vs. HBr Si etch DOE with oxide mask



Oxford Cobra ICP
HBr/Ar vs. HBr Si etch DOE with oxide mask

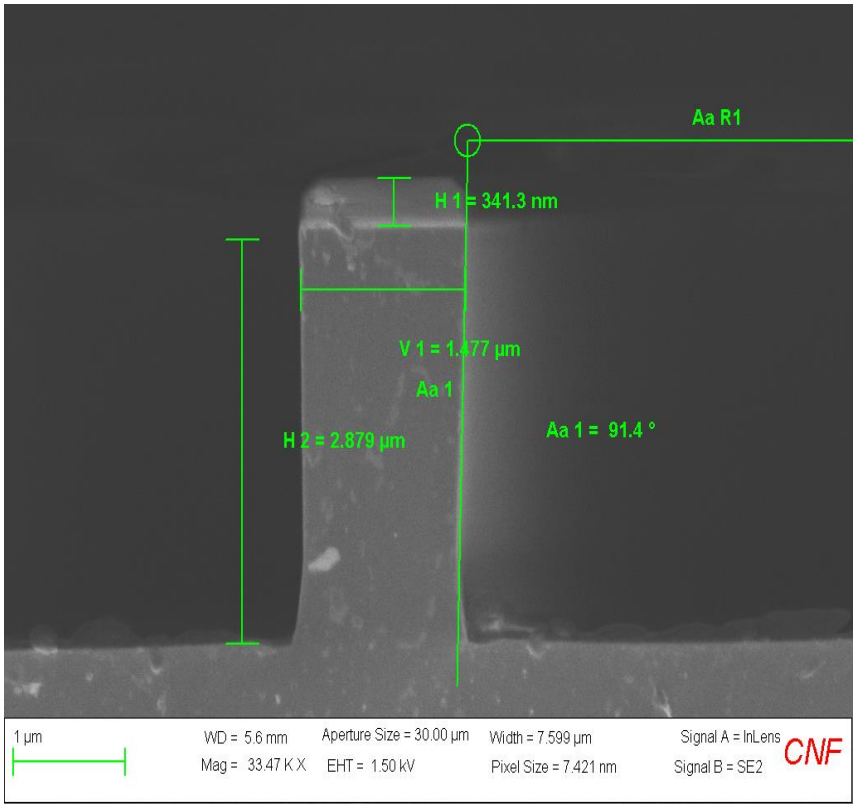


Oxford Cobra ICP
HBr/Ar vs. HBr Si etch DOE with oxide mask

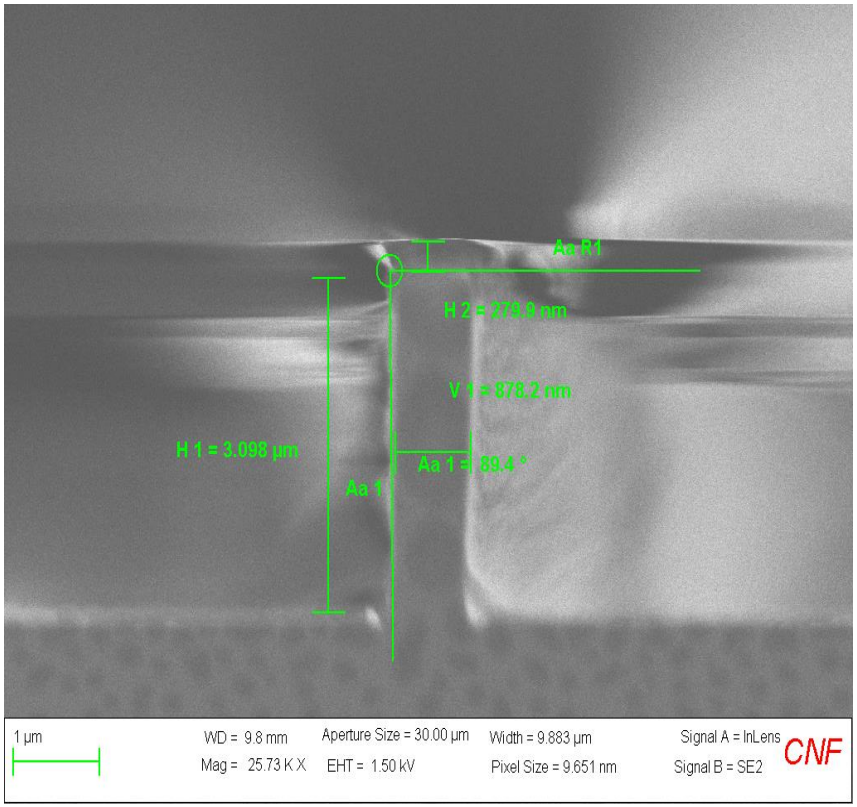


Oxford Cobra ICP
HBr Si etch DOE with oxide mask

HBr=20, ICP/RIE=1700W/30W, 5mtorr
ER=260nm/min, Sox=15:1

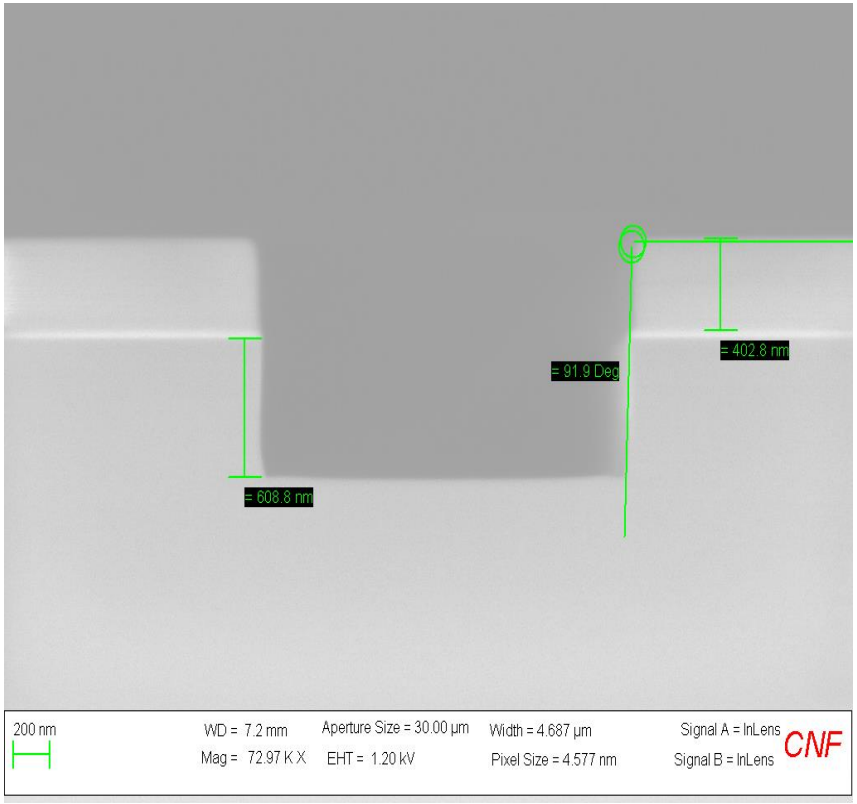


HBr=20, ICP/RIE=1900W/30W, 8mtorr
ER=267nm/min, Sox=19:1

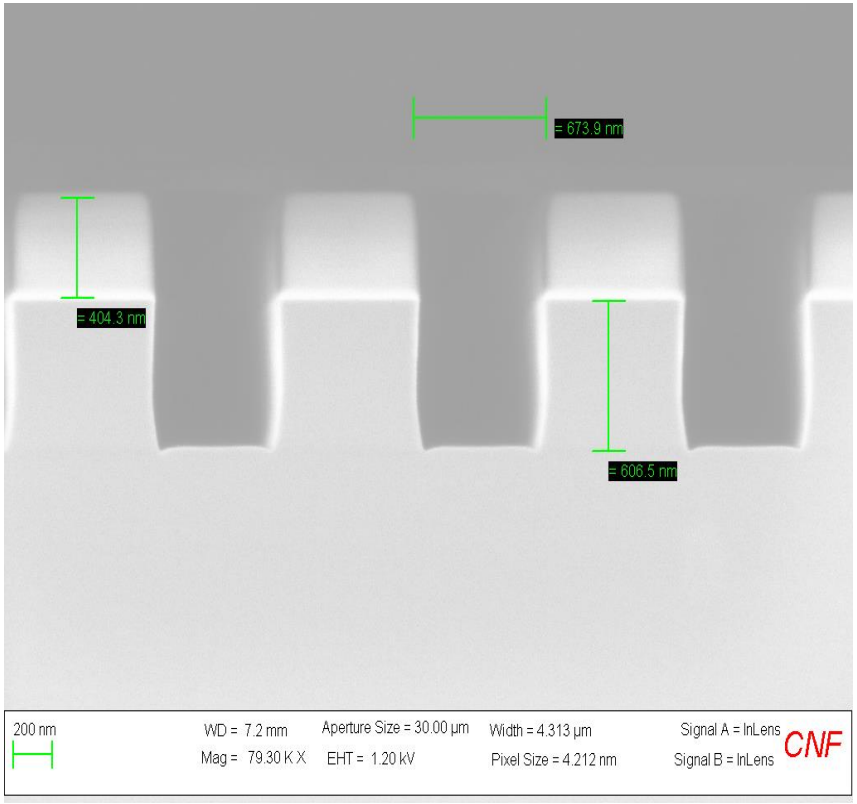


Oxford Cobra ICP
HBr Si etch DOE with oxide mask

HBr=20, ICP/RIE=1300W/40W, 5mtorr
ER=152nm/min, Sox=14:1

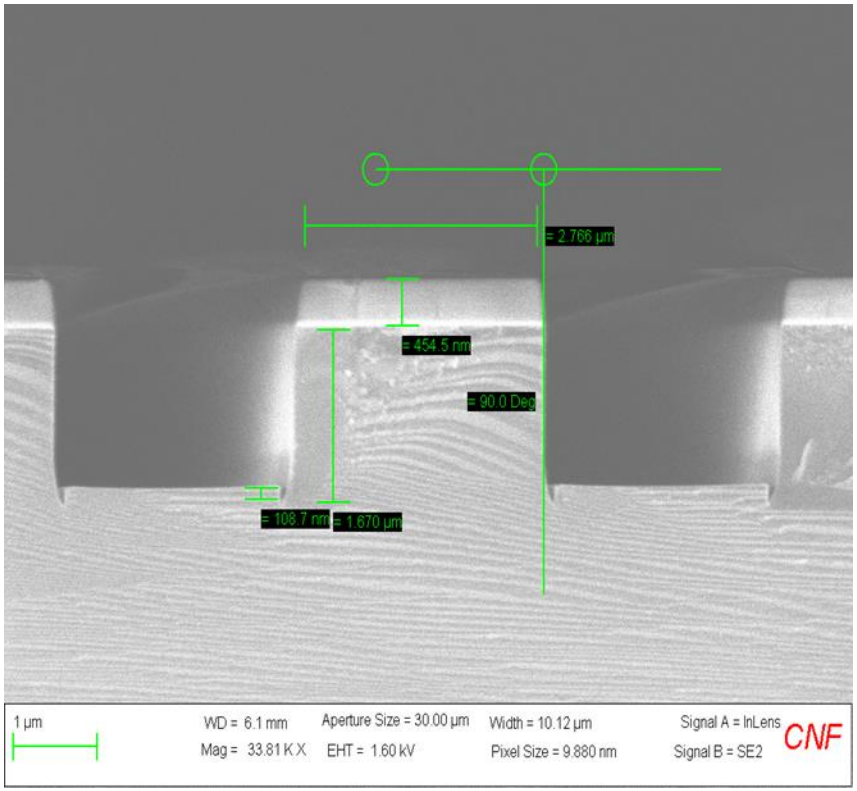


HBr=20, ICP/RIE=1300W/40W, 5mtorr
ER=152nm/min, Sox=14:1

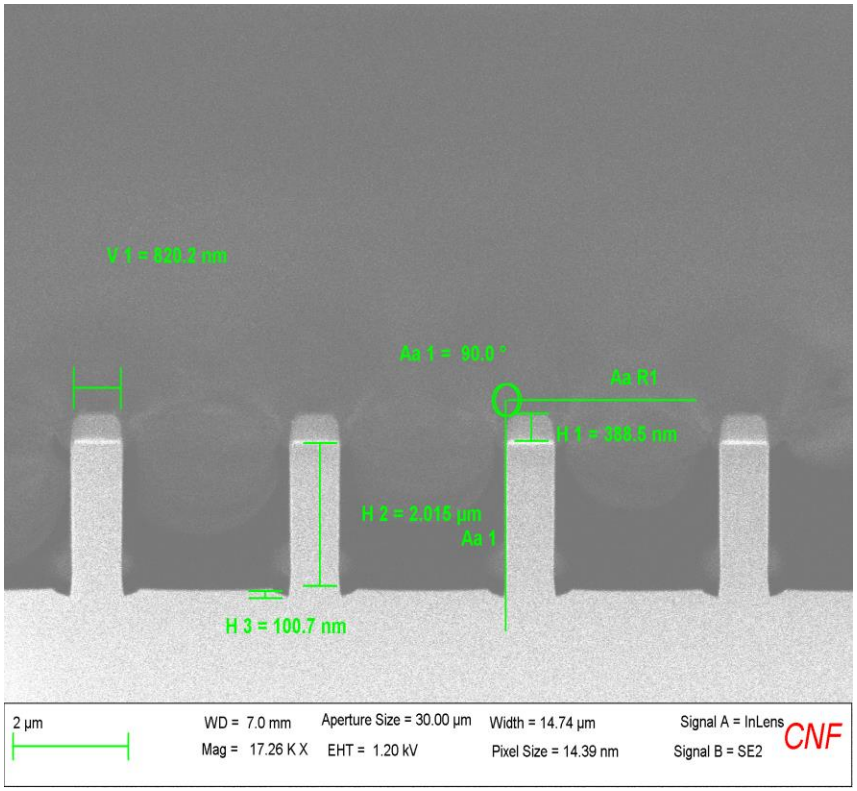


Oxford Cobra ICP
HBr/Ar Si etch DOE with oxide mask

HBr/Ar=20/7, ICP/RIE=1500W/30W, 11mtorr
ER=156nm/min, Sox=27:1



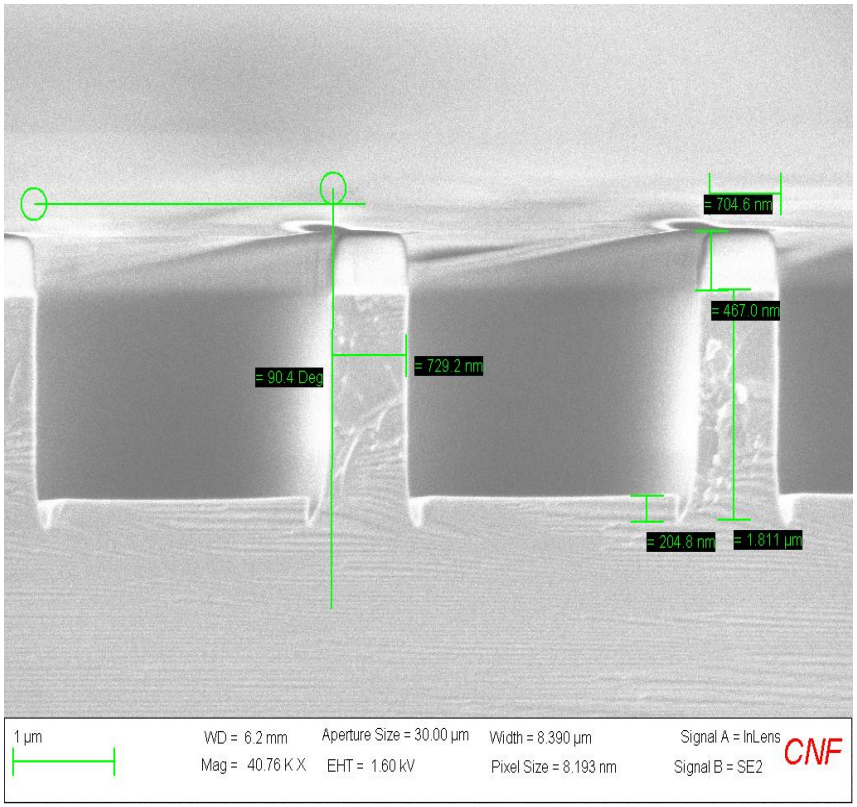
HBr/Ar=20/10, ICP/RIE=1500W/40W, 8mtorr
ER=202nm/min, Sox=16:1



Oxford Cobra ICP
HBr/Ar Si etch DOE with oxide mask

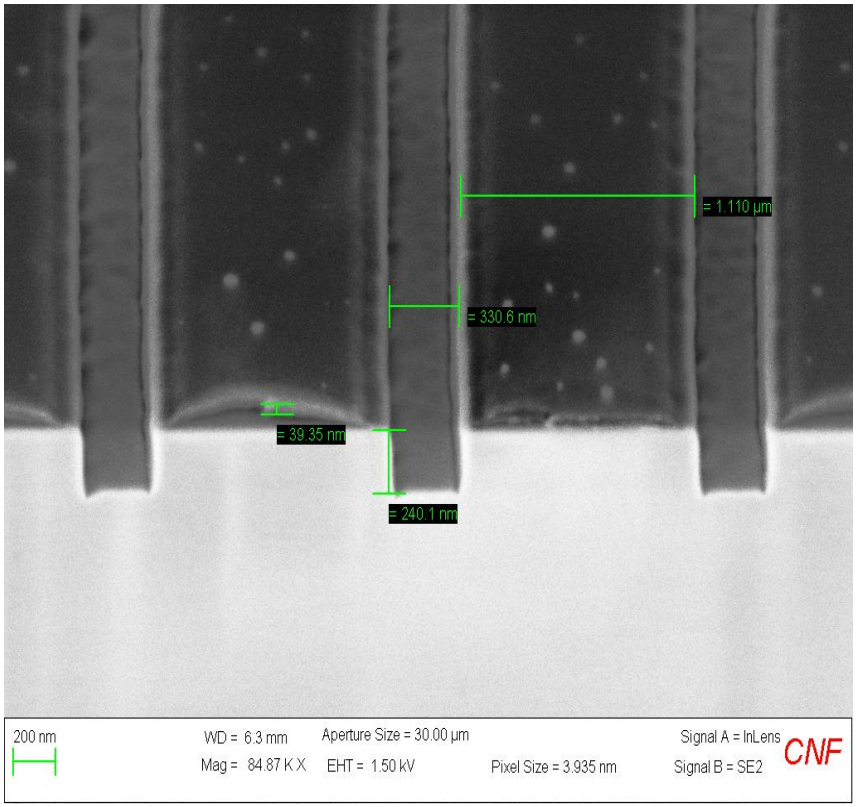
HBr/Ar=20/4, ICP/RIE=1900W/30W, 8mtorr
ER=273nm/min, Sox=20:1

HBr/Ar=20/7, ICP/RIE=1500W/30W, 11mtorr
ER=156nm/min, Sox=27:1

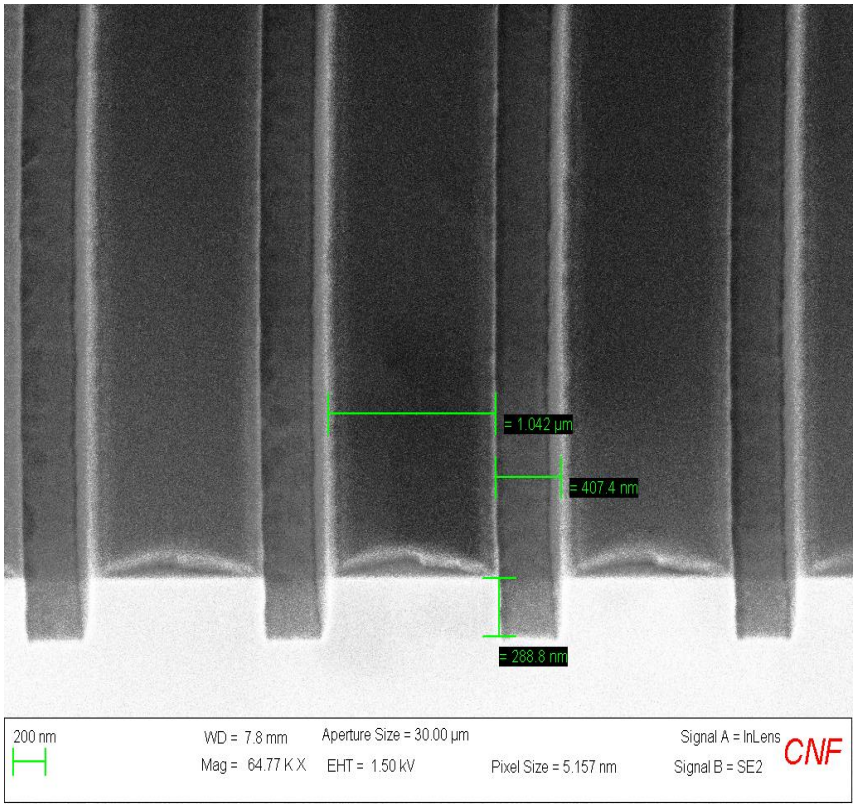


Oxford Cobra ICP
HBr Si etch of thermal nanoimprint lithography (TNIL) features

HBr=20, ICP/RIE=2200W/40W, 11mtorr
ER=140nm/min, SNILR=4:1

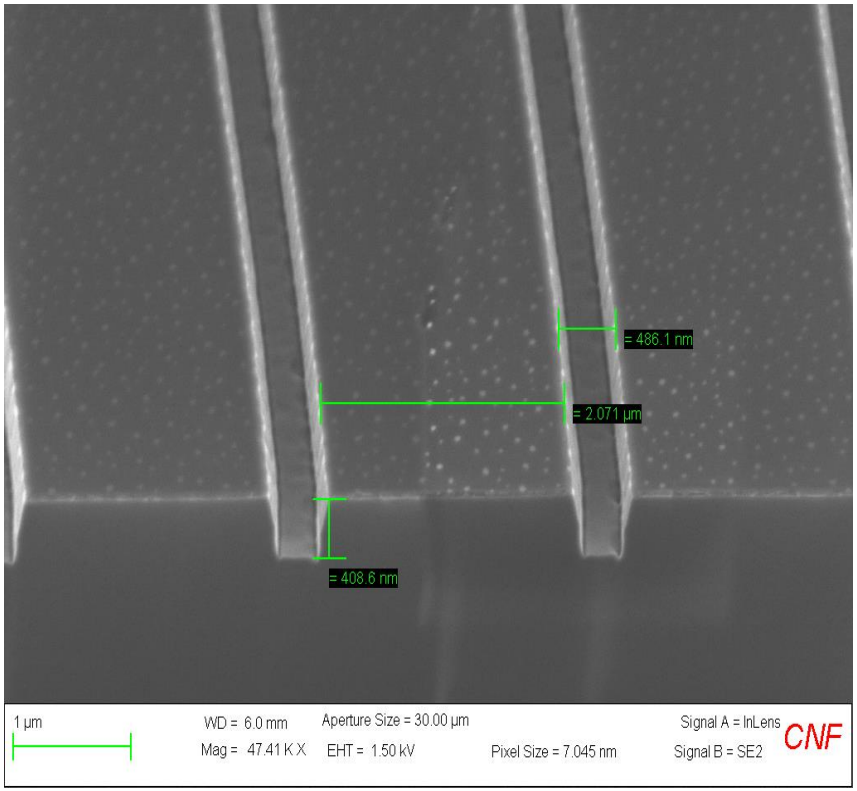


HBr=20, ICP/RIE=2200W/30W, 5mtorr
ER=193nm/min, SNILR=4:1

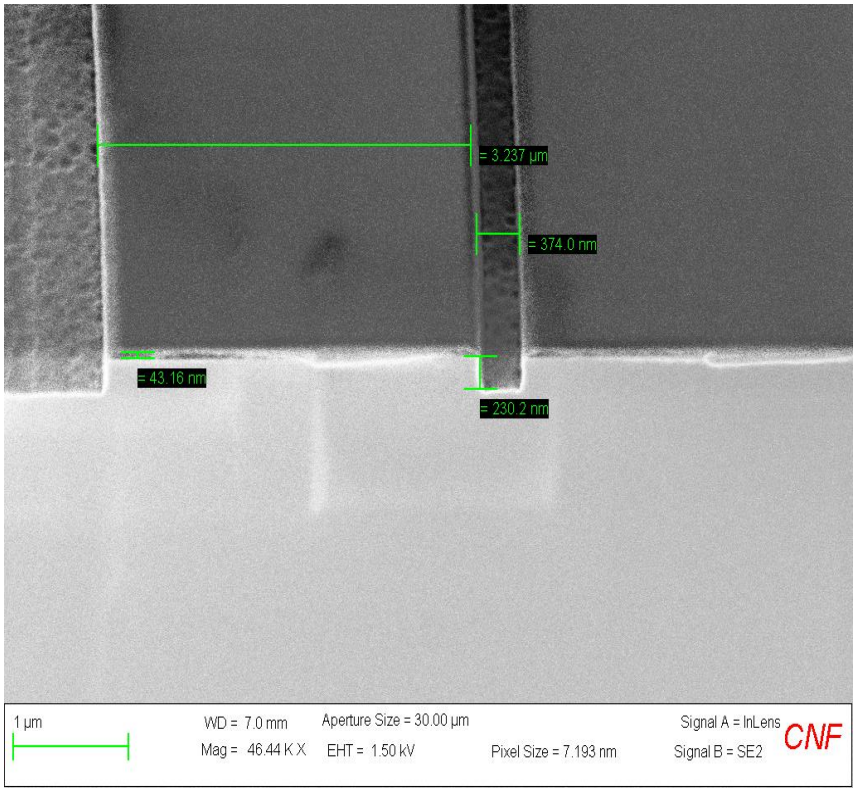


Oxford Cobra ICP
HBr Si etch of thermal nanoimprint lithography (TNIL) features

HBr=20, ICP/RIE=2000W/40W, 8mtorr
ER=234nm/min, SNILR=4:1



HBr/Ar=20/4, ICP/RIE=1500W/20W, 5mtorr
ER=165nm/min, SNILR=4:1



HBr based silicon etching conclusions

- A seasoned chamber is required for stable etch rates with the highest Br radical concentrations.
- H plays a vital role in the formation of volatile products and activation sites.
- Ion enhanced chemical sputtering is the key etch mechanism.
- Silicon etch rates are lower in HBr than Cl2 due to less surface adsorption coverage & lower ion flux.
- Selectivities to PR and oxide are higher with HBr than Cl2.
- The manifestation of etch artifacts such as micro trenching, faceting, and bowing are less likely with HBr than Cl2 possibly due to differences in the SPL and the angular etch yields.
- The addition of Ar to HBr results in lower etch rates and lower selectivity to PR and oxide.
- Demonstrated selectivity to PR of 3.5-7:1
- Demonstrated selectivity to oxide of 15-27:1
- Applied to 300nm TNIL features with selectivity of 4:1
- Future work:
  - application to SOI with the goal of very high selectivity to BOX.
  - application of low frequency bias with the goal of minimizing RIE LAG.