*NNCI ETCH WORKSHOP*
*Cornell University*
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# Highly selective silicon nitride to silicon oxide etch process in Oxford 100 ICP

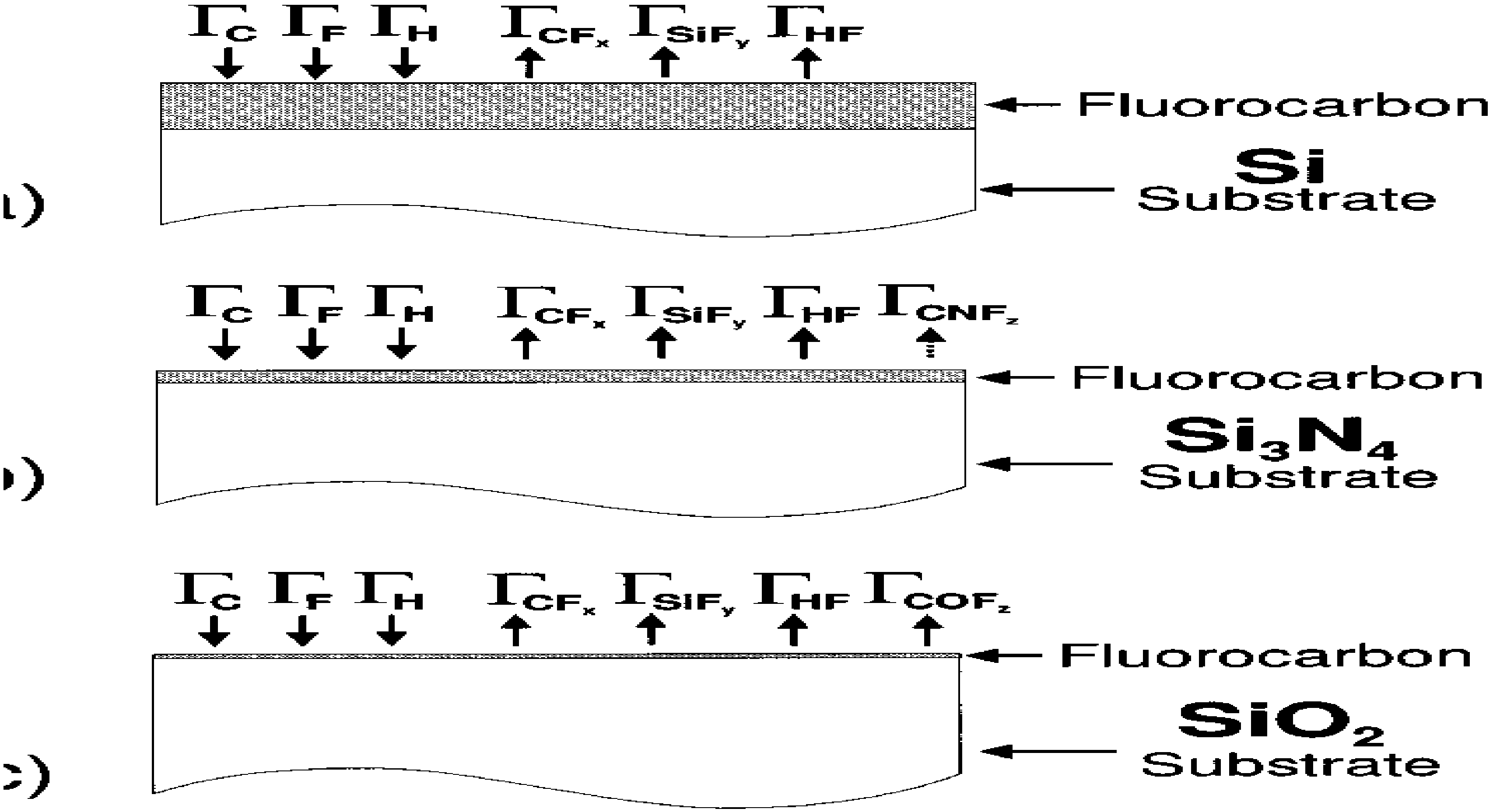
**Vince Genova**

**CNF Research Staff**

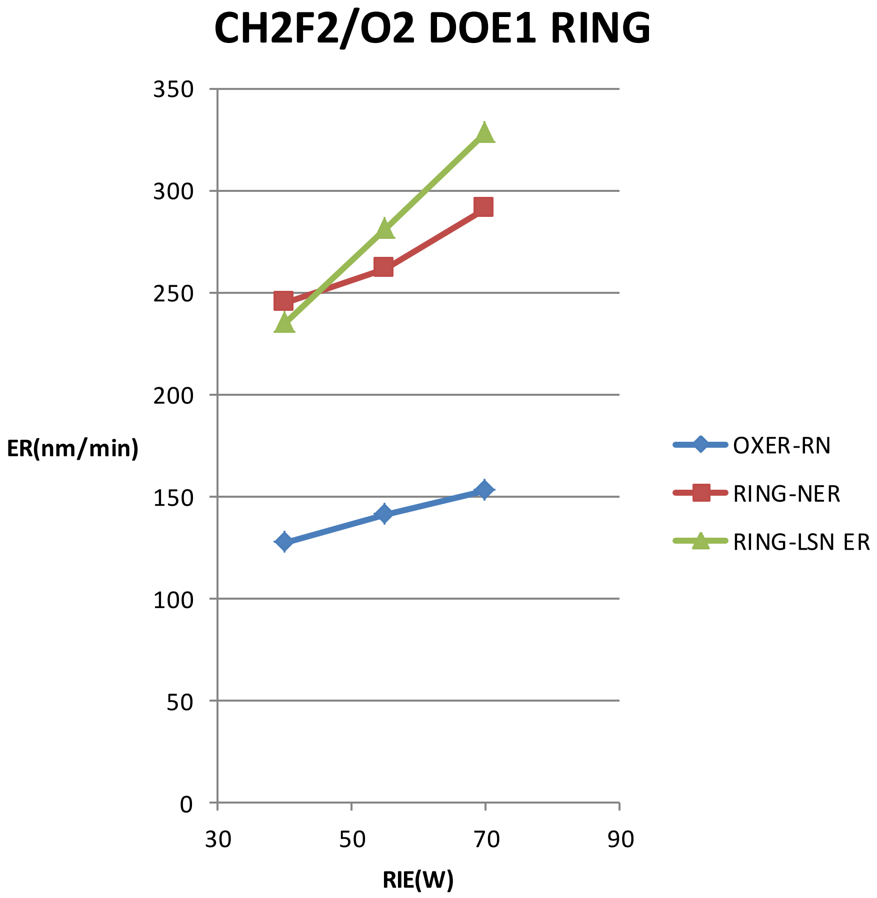
# Introduction and background

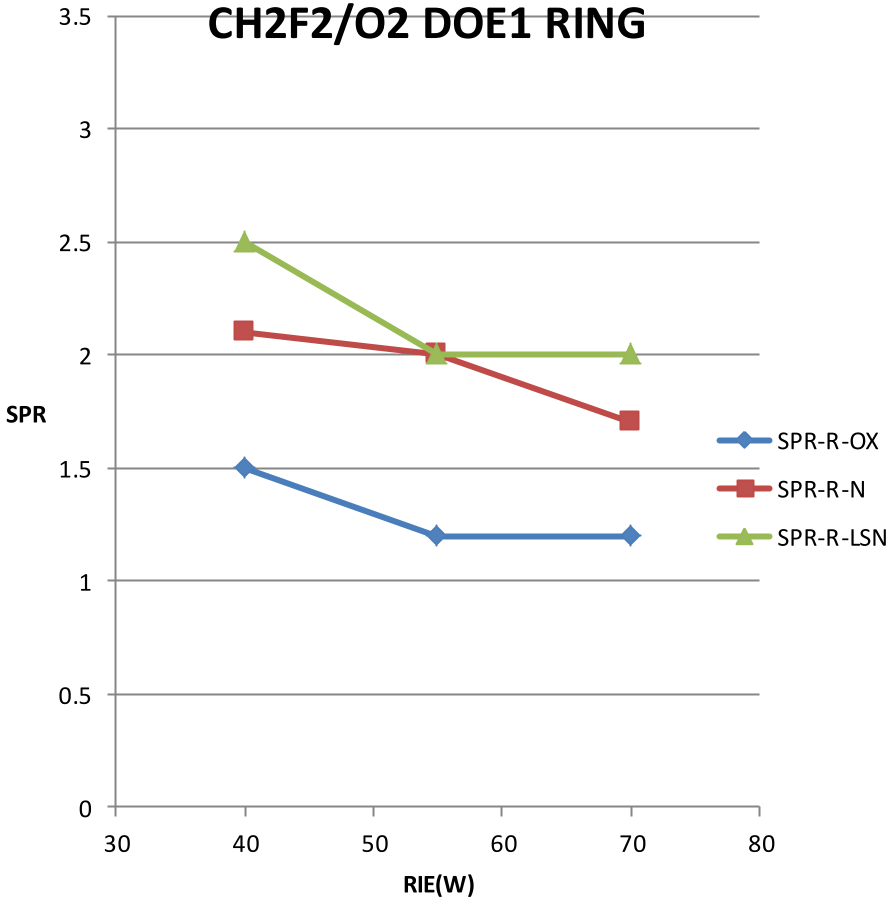
- Selective silicon nitride to silicon oxide etching has many applications, the main one being in the formation of gate sidewall spacers in MOSFETs.
- Si3N4 is insulating with high thermal stability & is a barrier against dopant diffusion.
- The gate spacer helps to accurately define the channel length, the S/D doping profile, & helps eliminate short channel effects.
- High selectivity is needed to accurately stop on the underlying SiO2 which can 1-2nm thick.
- In F based plasmas, nitride etch behavior is closer to Si than SiO2.
- Nitride etching is more dependent on F concentration and less dependent on ion bombardment.
- Nitride’s ability to consume fluorocarbon deposited layer is closer to that of silicon oxide.
- Relative etch rates of nitride and oxide are largely determined by the FC interaction layer thicknesses and the C:F:H ratio in the plasma chemistry.
- H radicals from polymer forming gases (CHF3, CH2F2) promote the removal of N from Si3N4 by generating HCN etch products and reducing the FC deposition on silicon nitride relative to that of silicon oxide.
- SF6 is the best choice to achieve high selectivity of nitride to oxide due to the large generation of atomic F along with relatively low DC bias.
- The addition of CH2F2 contributes atomic H in the formation of the HFC polymer on the respective nitride and oxide surfaces which influences the differential etch rates and also enhances PR selectivity along with the formation of sidewall protection layer for anisotropic patterning.

# Polymer blocking ability



# CH2F2/O2 dielectric comparison ring DOE





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# Background (con’t)

- N2 is an important etch product in silicon nitride etching.
- Desorption of nitrogen can often be the limiting factor in nitride etching.
- The addition of N2 to the plasma etch chemistry can enhance the nitride etch rate.
- Dissociated N atoms can adsorb on the activated nitride surface forming N2 as a reaction product.
- The addition of N2 to SF6 can enhance the dissociation of SF6 to atomic F by changing the overall electron energy distribution.
- The enhanced F concentration will have a much greater influence on the nitride ER.
- N2 addition also dilutes the polymer forming chemistry thereby reducing the HFC blocking layer and enhancing the nitride etch rate.
- Relatively low bias conditions would favor the etching the nitride to oxide due to the relative bond strengths. (achieved with SF6 and polymer forming CH2F2)
- Proper choice of plasma chemistry and parameters is key to differentiating the respective etch rates of silicon nitride and silicon oxide.

i-line PR masked selective etching of LPCVD $Si_3N_4$ and low stress $Si_3N_4$ (Si rich) over thermal $SiO_2$ with novel $SF_6$-$CH_2F_2$-$N_2$ gas mixture. $CH_2F_2$ through gas

1x1cm $Si_3N_4$, LSN and $SiO_2$ pieces bonded to 100mm sapphire carrier wafer with Cool Grease

No preheat between runs

MATRIX EXPERIMENTS

| Run | RIE | ICP | $CH_2F_2$ | Pre |
|---|---|---|---|---|
| 1 | 3 | 1200 | 4 | 9 |
| 2 | 3 | 1600 | 8 | 12 |
| 3 | 3 | 2000 | 12 | 15 |
| 4 | 5 | 1200 | 8 | 15 |
| 5 | 5 | 1600 | 12 | 9 |
| 6 | 5 | 2000 | 4 | 12 |
| 7 | 7 | 1200 | 12 | 12 |
| 8 | 7 | 1600 | 4 | 15 |
| 9 | 7 | 2000 | 8 | 9 |

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

MEASURED RESULTS

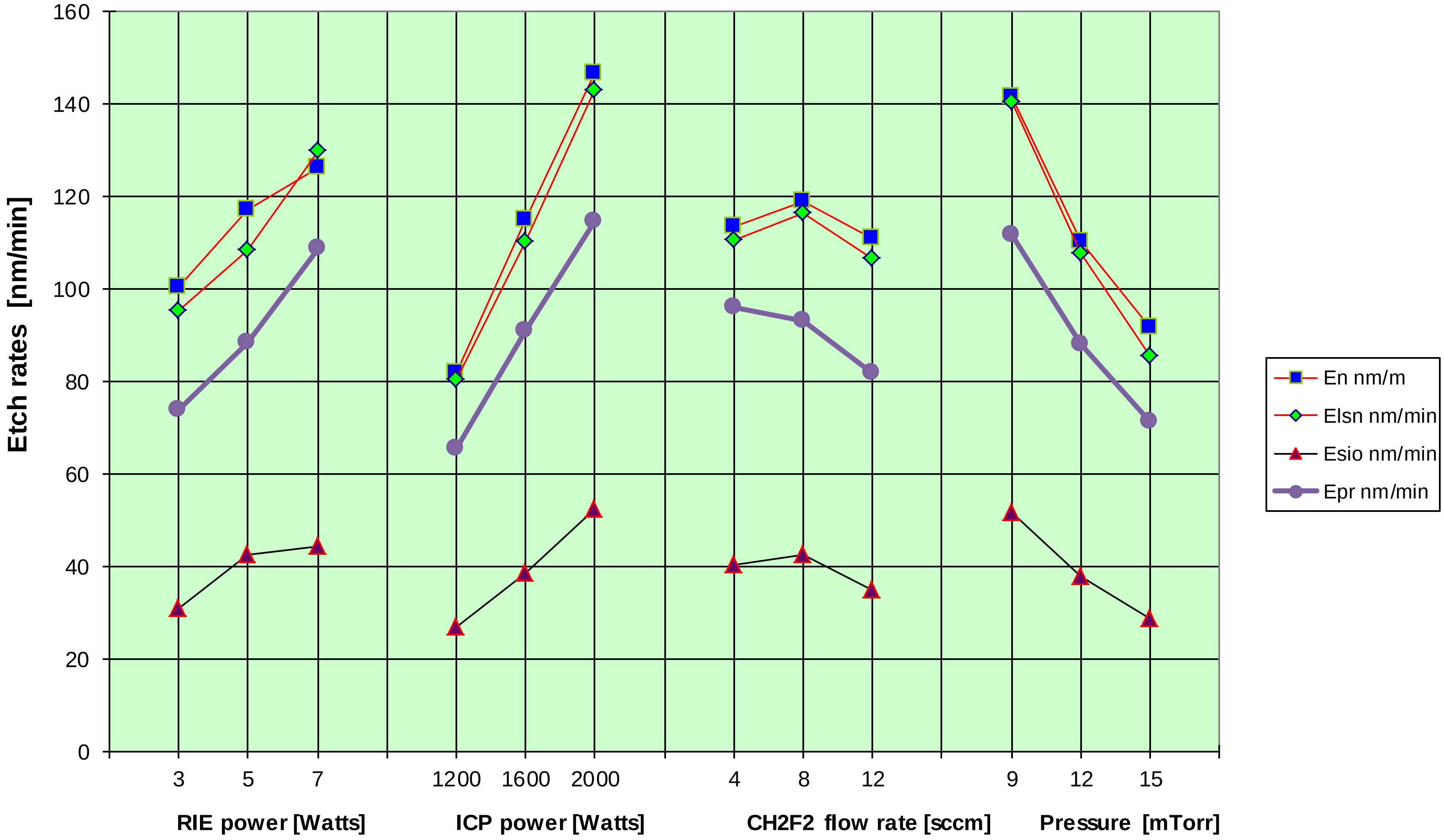
| Run | En nm/m | Elsn nm/min | Esio nm/min | Epr nm/min | Sn/o | Sn/pr | Slsn/o | Slsn/pr | DC [-V] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 94 | 93 | 32 | 76 | 2.94 | 1.24 | 2.91 | 1.22 | 65 |
| 2 | 101 | 96 | 32 | 75 | 3.16 | 1.35 | 3.00 | 1.28 | 65 |
| 3 | 106 | 97 | 29 | 71 | 3.66 | 1.49 | 3.34 | 1.37 | 67 |
| 4 | 66 | 57 | 23 | 47 | 2.87 | 1.40 | 2.48 | 1.21 | 105 |
| 5 | 141 | 132 | 50 | 102 | 2.82 | 1.38 | 2.64 | 1.29 | 73 |
| 6 | 144 | 136 | 55 | 116 | 2.62 | 1.24 | 2.47 | 1.17 | 76 |
| 7 | 86 | 91 | 26 | 73 | 3.31 | 1.18 | 3.50 | 1.25 | 110 |
| 8 | 103 | 103 | 34 | 96 | 3.03 | 1.07 | 3.03 | 1.07 | 115 |
| 9 | 190 | 196 | 73 | 157 | 2.60 | 1.21 | 2.68 | 1.25 | 76 |

| CONSTANT PARAMETERS | |
|---|---|
| $SF_6$ | 16sccm,through lid |
| $N_2$ | 4sccm, through lid |
| $CH_2F_2$ (variable) | Through gas ring |
| Temperature | 10deg |
| Backside He | 10Torr |
| Etch time | 1minute |

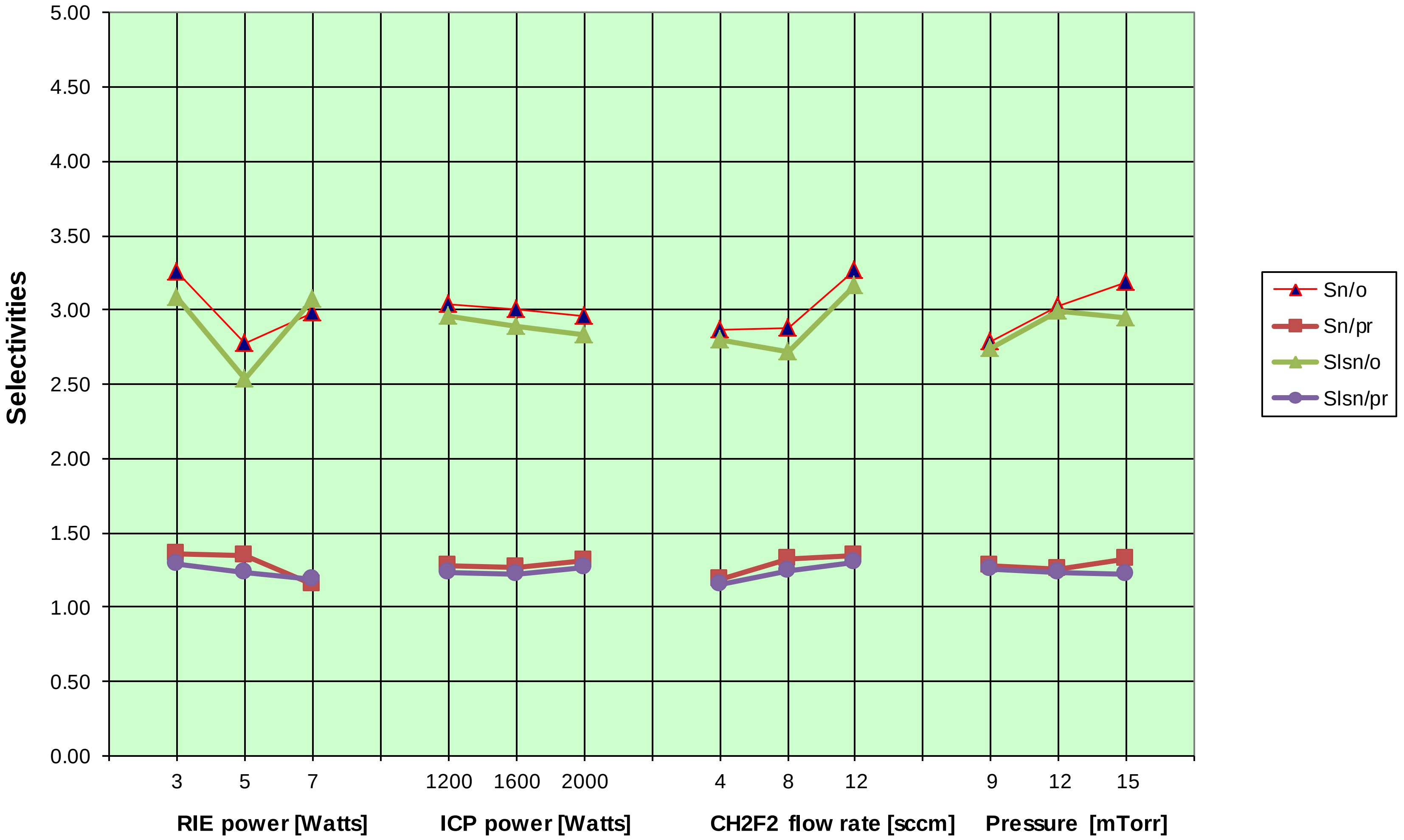
ERAGES (PLOTTED ON GRAPHS)

| Parameter | Level | En nm/m | Elsn nm/min | Esio nm/min | Epr nm/min | Sn/o | Sn/pr | Slsn/o | Slsn/pr | DC [-V] |
|---|---|---|---|---|---|---|---|---|---|---|
| RIE | 3 | 100 | 95 | 31 | 74 | 3.25 | 1.36 | 3.08 | 1.29 | 66 |
| | 5 | 117 | 108 | 43 | 88 | 2.77 | 1.34 | 2.53 | 1.23 | 85 |
| | 7 | 126 | 130 | 44 | 109 | 2.98 | 1.15 | 3.07 | 1.19 | 100 |
| ICP | 1200 | 82 | 80 | 27 | 65 | 3.04 | 1.27 | 2.96 | 1.23 | 93 |
| | 1600 | 115 | 110 | 39 | 91 | 3.00 | 1.27 | 2.89 | 1.22 | 84 |
| | 2000 | 147 | 143 | 52 | 115 | 2.96 | 1.31 | 2.83 | 1.26 | 73 |
| $CH_2F_2$ | 4 | 114 | 111 | 40 | 96 | 2.86 | 1.18 | 2.80 | 1.16 | 85 |
| | 8 | 119 | 116 | 43 | 93 | 2.88 | 1.32 | 2.72 | 1.25 | 82 |
| | 12 | 111 | 107 | 35 | 82 | 3.26 | 1.35 | 3.16 | 1.30 | 83 |
| Pre | 9 | 142 | 140 | 52 | 112 | 2.79 | 1.28 | 2.74 | 1.26 | 71 |
| | 12 | 110 | 108 | 38 | 88 | 3.03 | 1.26 | 2.99 | 1.23 | 84 |
| | 15 | 92 | 86 | 29 | 71 | 3.18 | 1.32 | 2.95 | 1.22 | 96 |

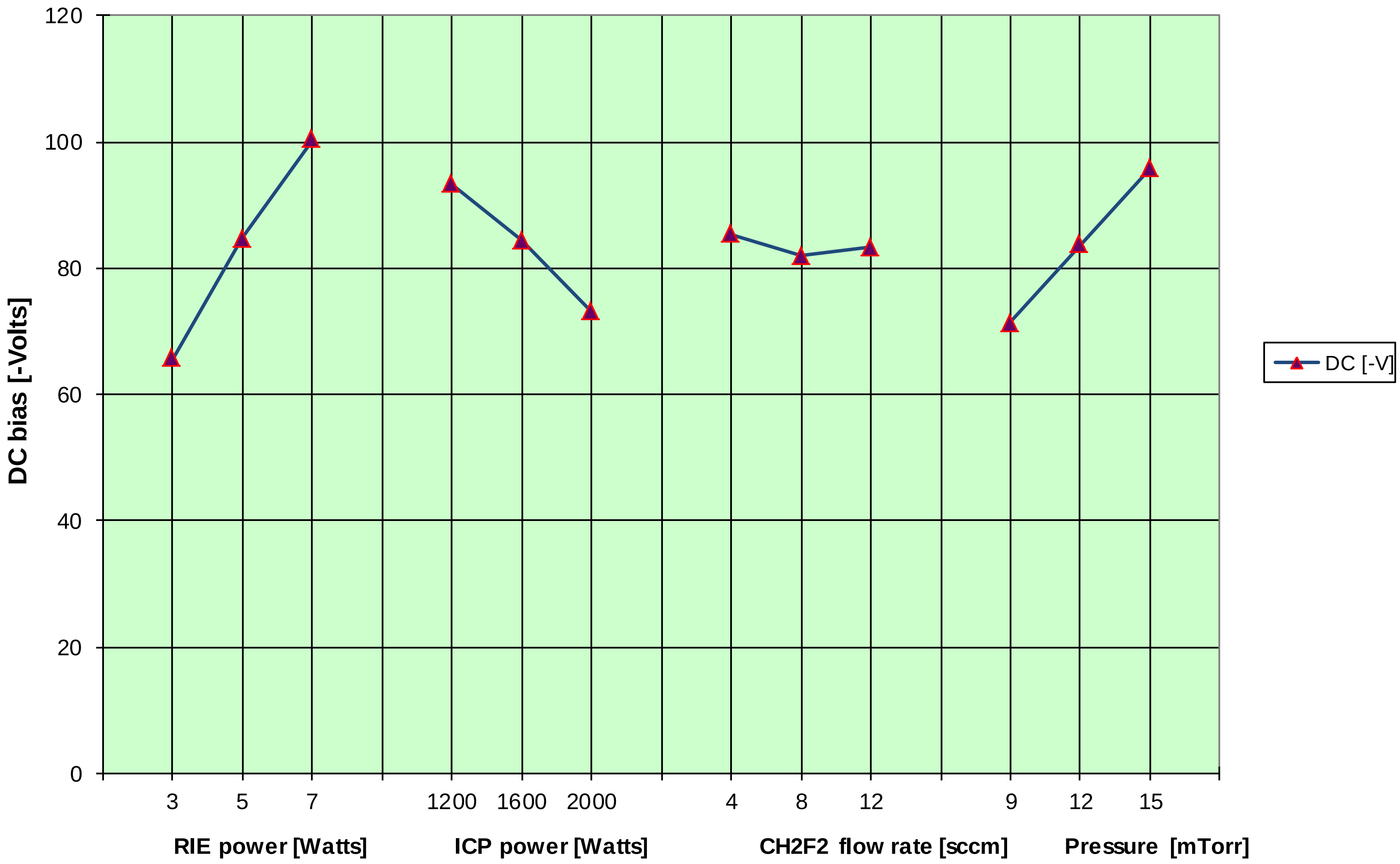
# Si3N4, LSN, SiO2 and PR etch rates for selective Si3N4 etching SF6-CH2F2-N2



# Selectivities for selective Si3N4 etching with SF6-CH2F2-N2

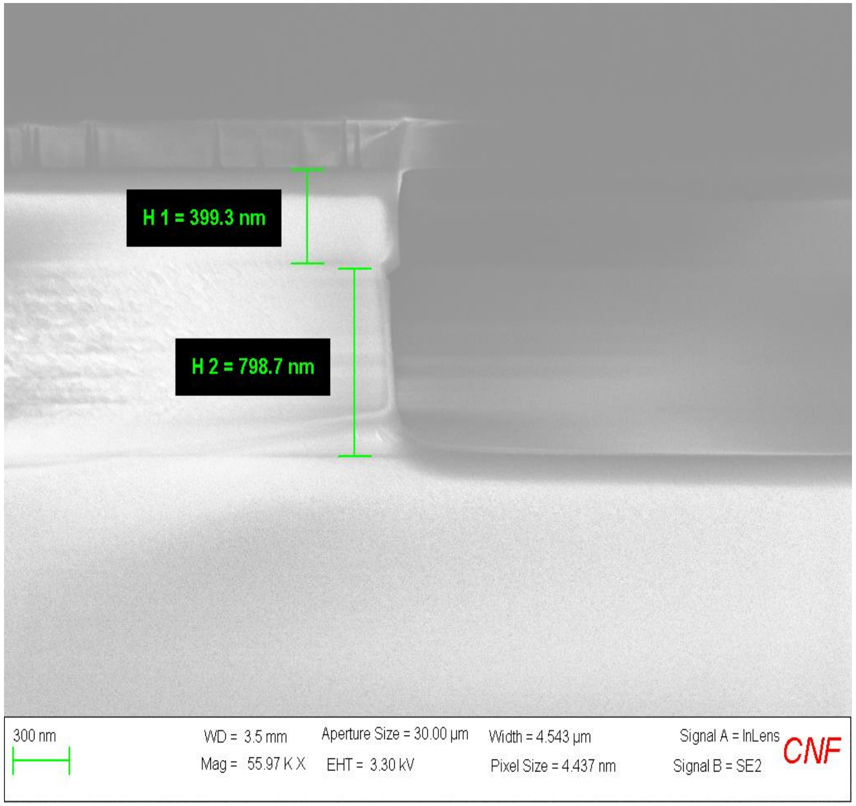


# DC bias for selective Si3N4 etching with SF6-CH2F2-N2

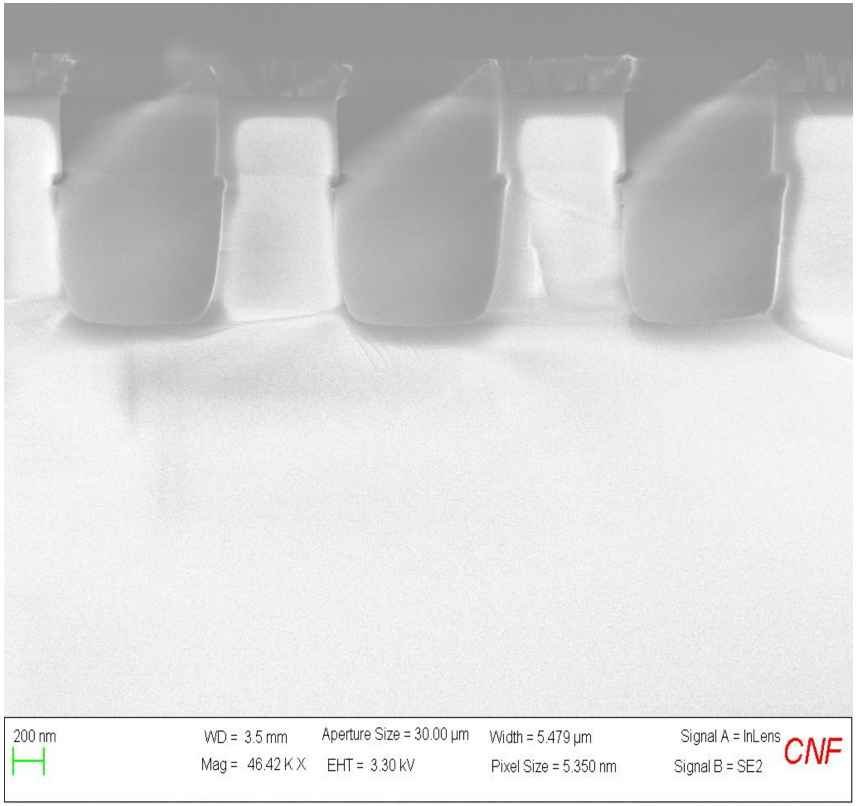


# SF6/CH2F2/N2 selective SiN to SiO2
# Oxford 100 ICP

SF6/CH2F2/N2=16/12/4, ICP/RIE=1200W/3W, 15mtorr, ER(SiN)=91nm/min, Sox=4.4:1



SF6/CH2F2/N2=16/12/4, ICP/RIE=1200W/3W, 15mtorr, ER(SiN)=91nm/min, Sox=4.4:1



# Conclusions from the DOE

- Greatest influences on the selectivity of silicon nitride to silicon oxide are
  1. RIE power
  2. CH2F2 flow
  3. pressure
- RIE power-lower power favors the nitride etch rate, lower Si-N bond strength
- CH2F2 flow-addition of H with greater CH2F2 flow affects the plasma chemistry favoring the nitride etch rate by formation of HCN etch products and the reduction in polymer thickness
- Pressure-increasing pressure increases the chemical nature of the plasma via an increase in radicals favoring the nitride etch rate.
- Chemistry and plasma parameters are vital to achieving high nitride to oxide selectivities of 3.5-4.5:1.