Use of Spectrograph-based OES for SiN Etch Selectivity and Endpoint Optimization

F. G. Celii and C. Huffman
Texas Instruments, Inc., Dallas, TX, USA

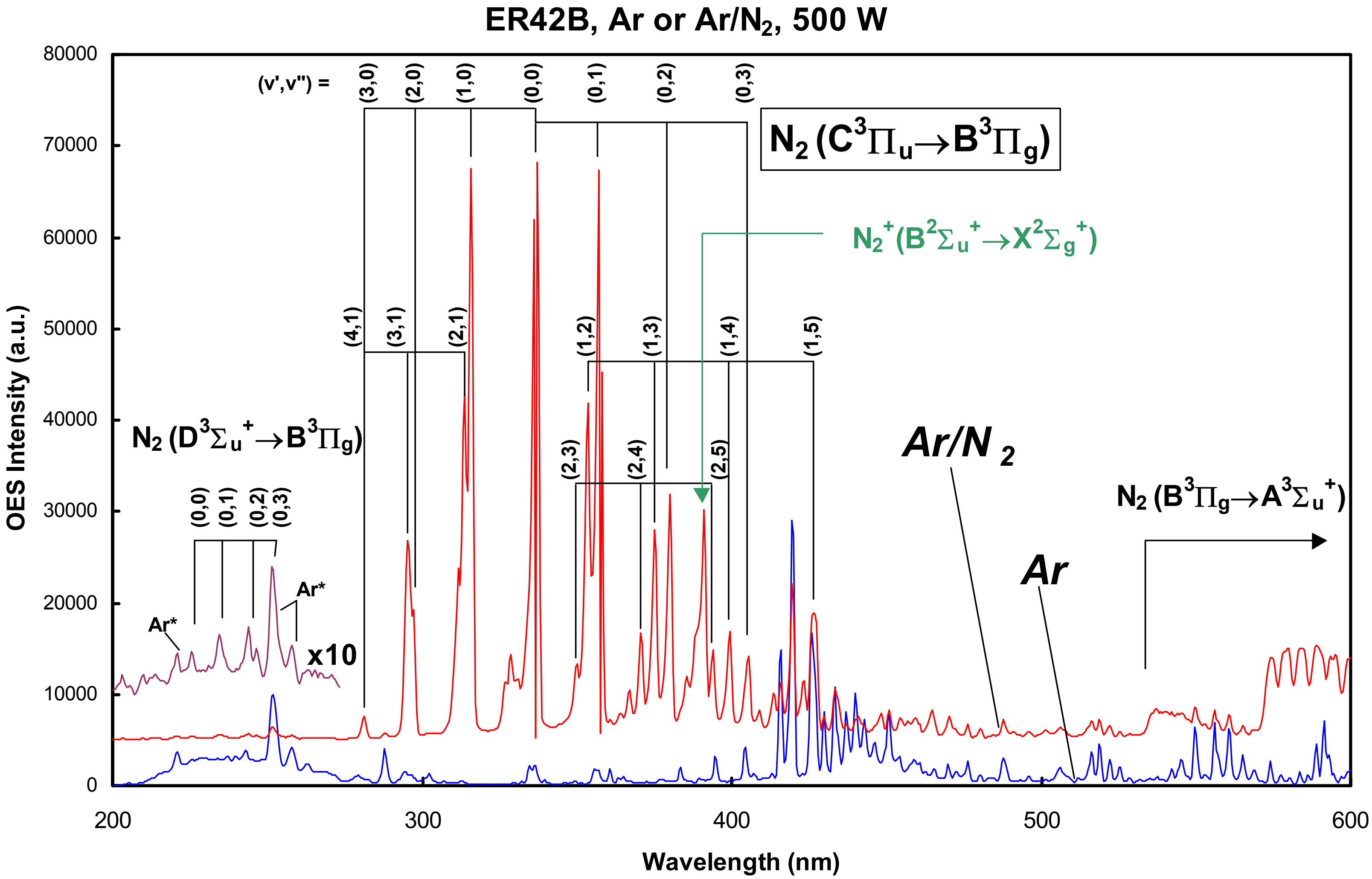
J. Hosch* and K. Harvey
Verity Instruments, Carrollton, TX, USA

*Presenter

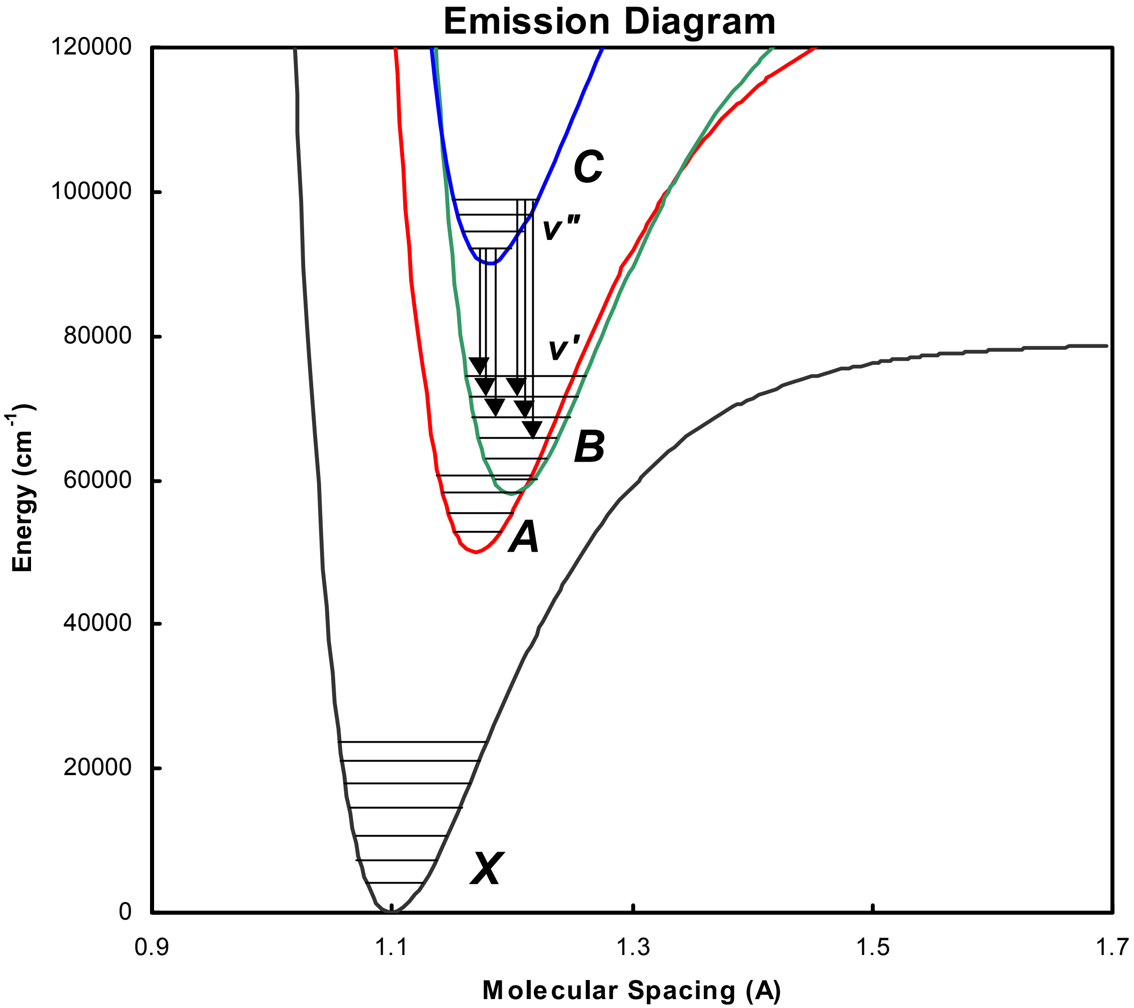
Goals of the Project

- Develop a new process for etching SiN
  - NO + F are active etch species in SiN etch
  - Kastenmeier, Matsuo and Oehrlein, J. Vac. Sci. Technol., A17 (1999) 3179
- Use $N_2 + O_2$ with CH_2F_2 in Ar to generate NO in the chamber
- Determine optimum gas mix for rapid etch
- Use OES to monitor NO concentration
- Use OES to detect endpoint

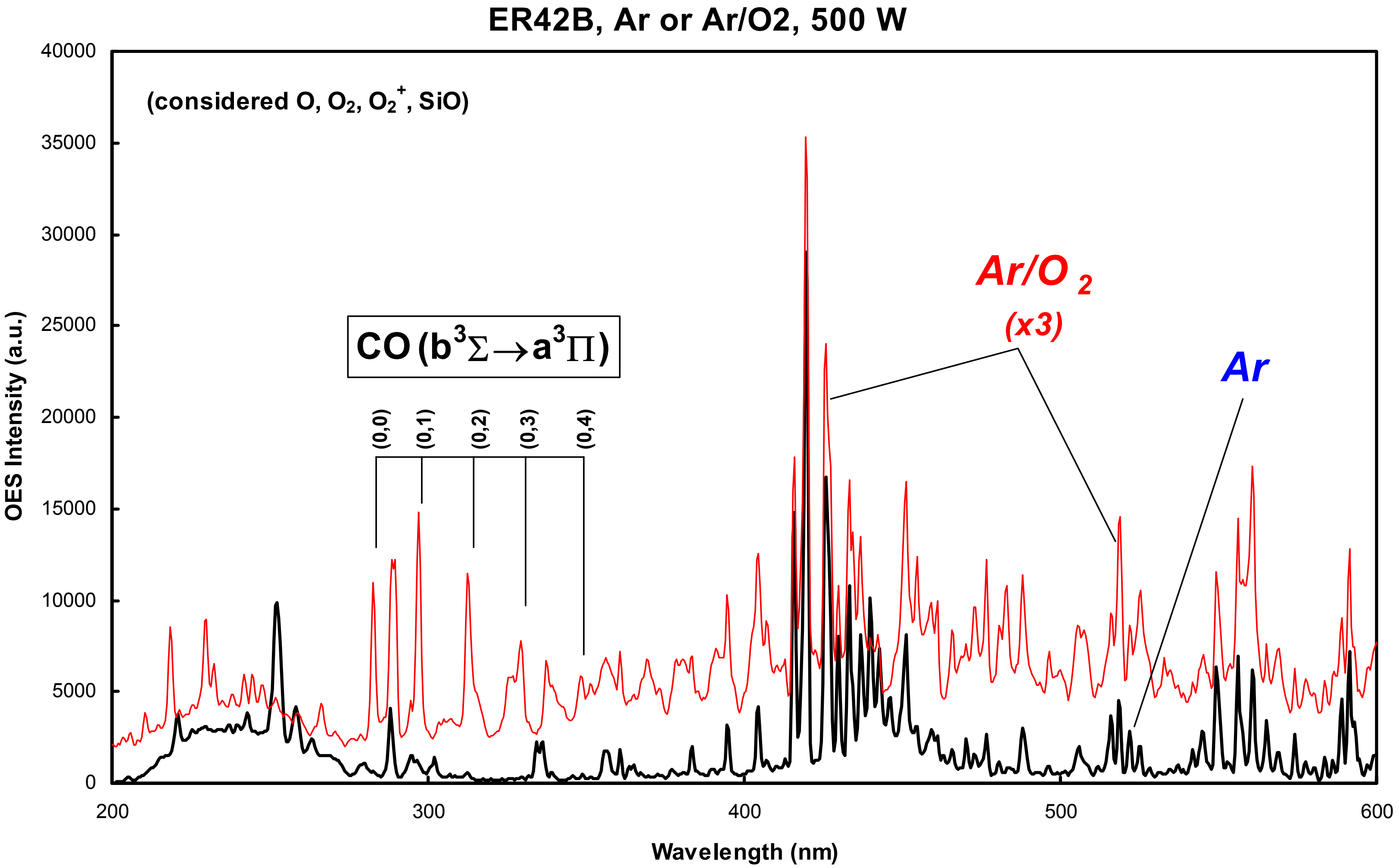
Ar AND Ar/N_2 PLASMA OES



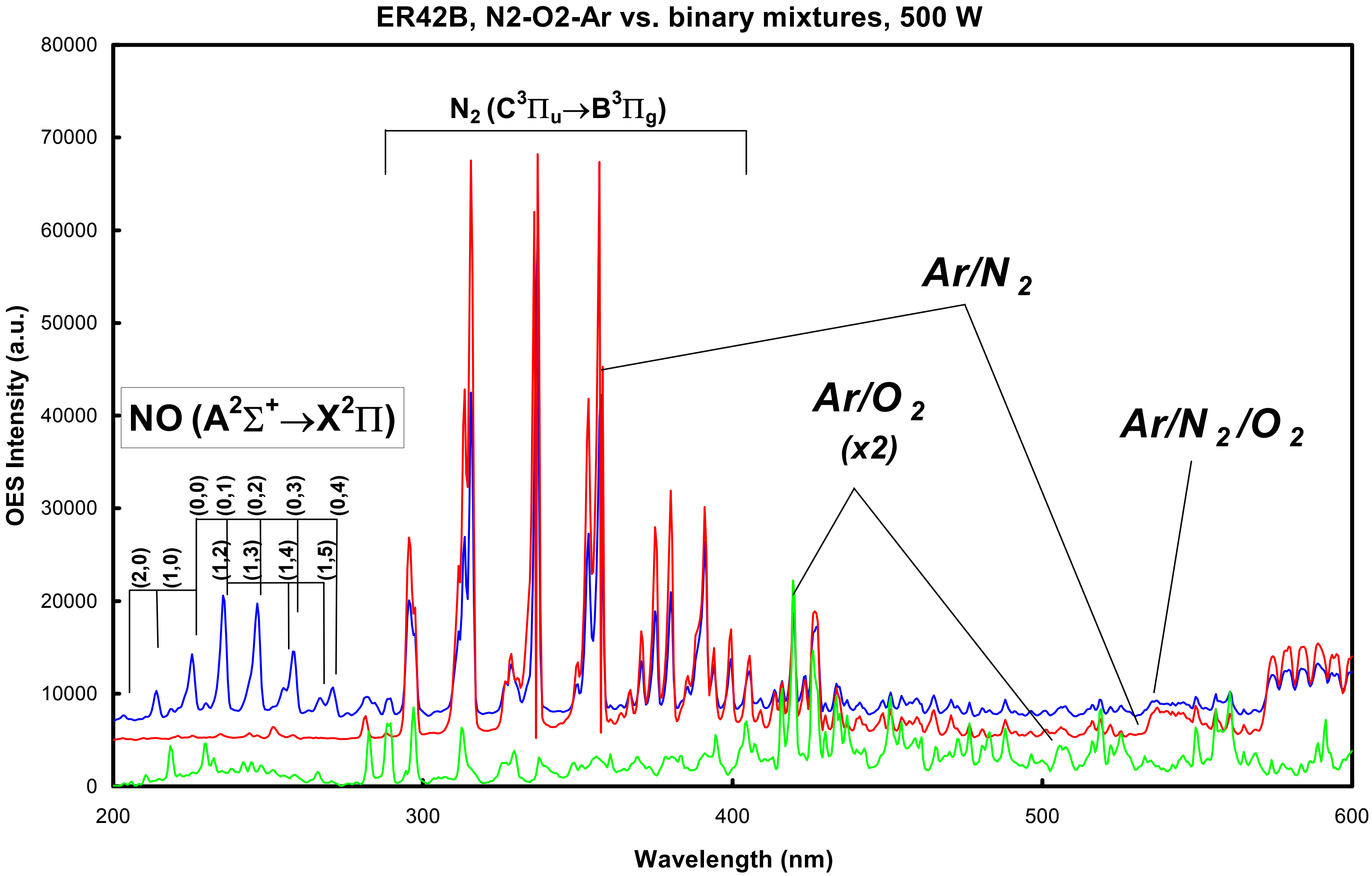
OES TRANSITIONS



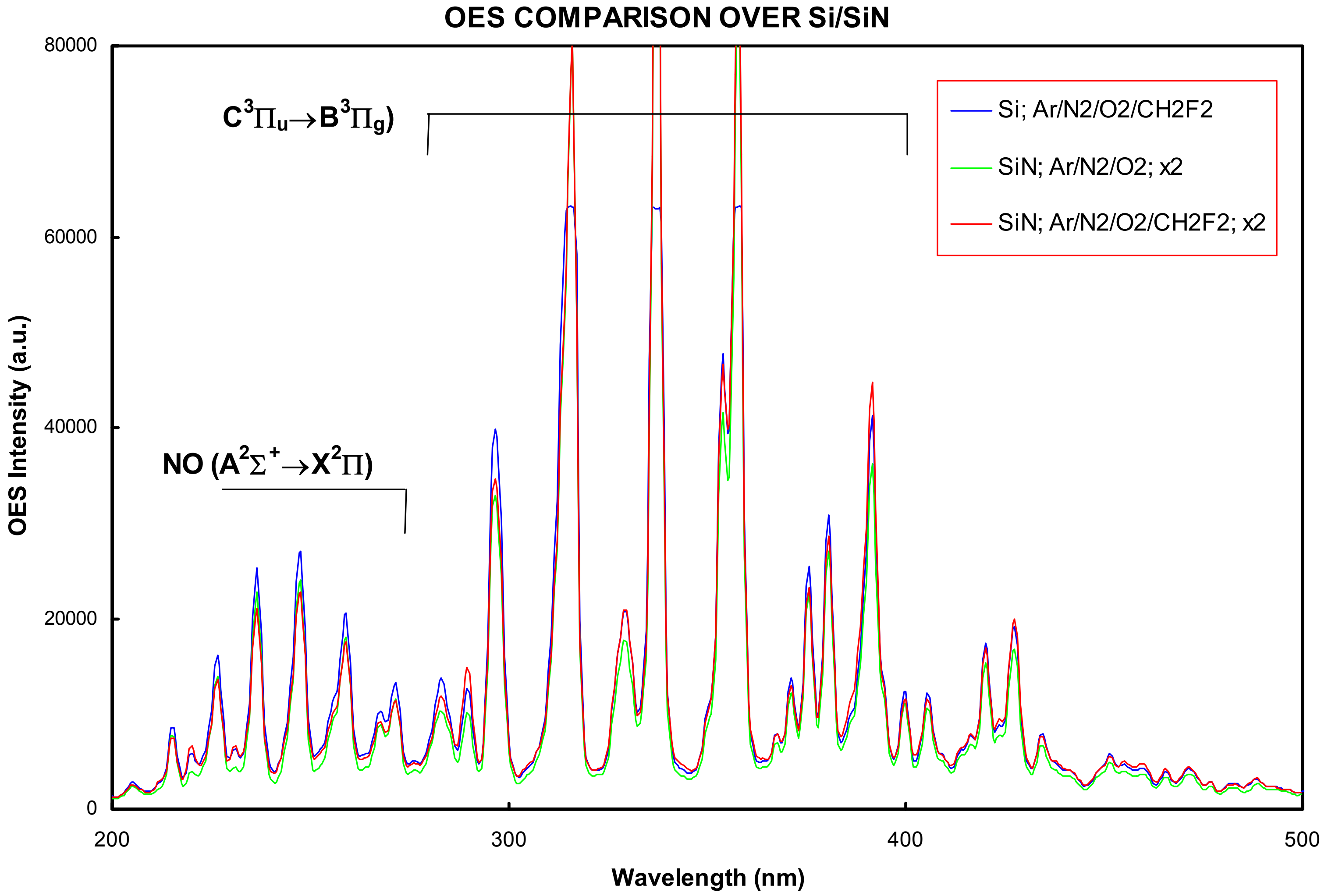
Ar AND Ar/O_2 PLASMA OES



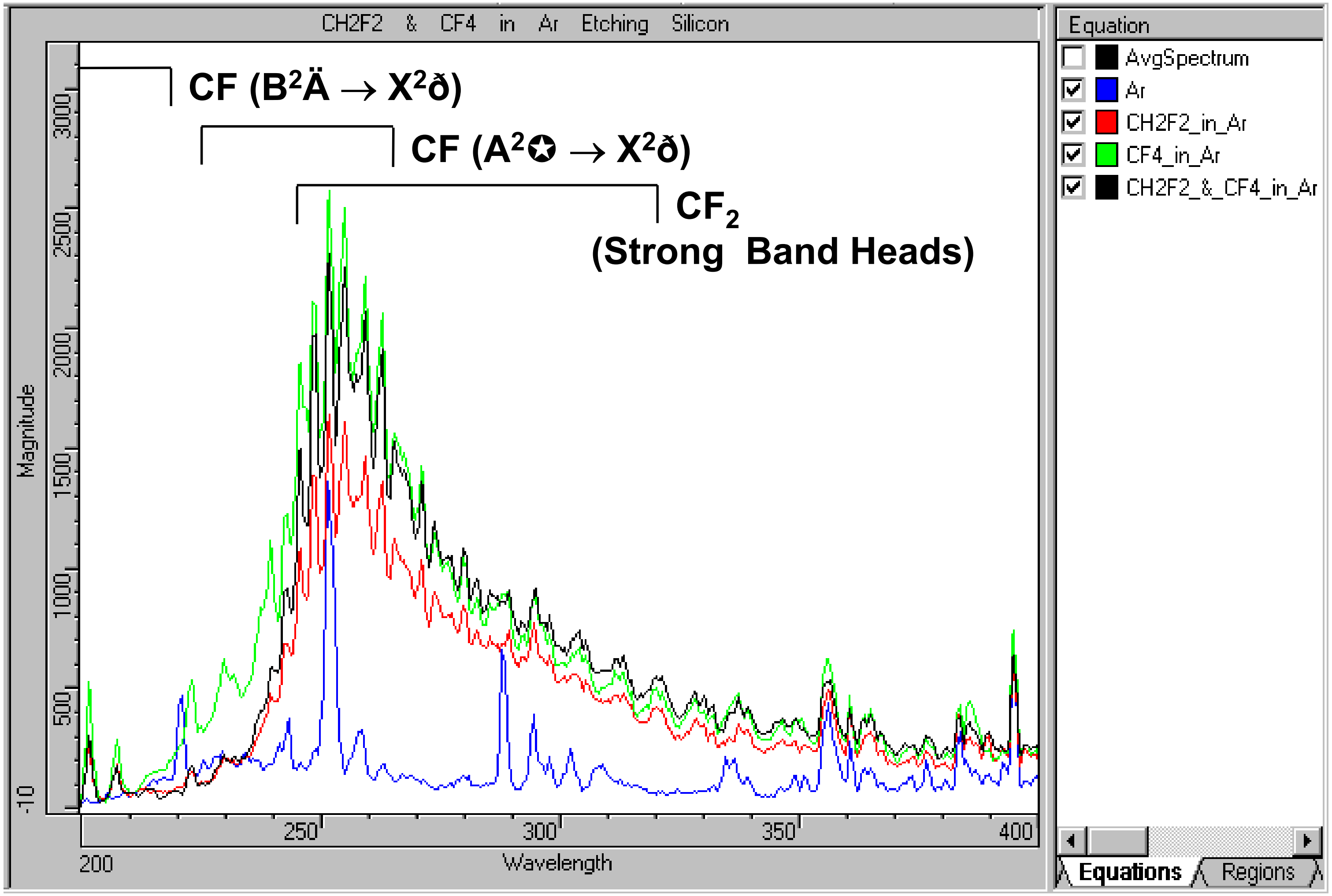
Ar/N_2 /O_2 PLASMA OES



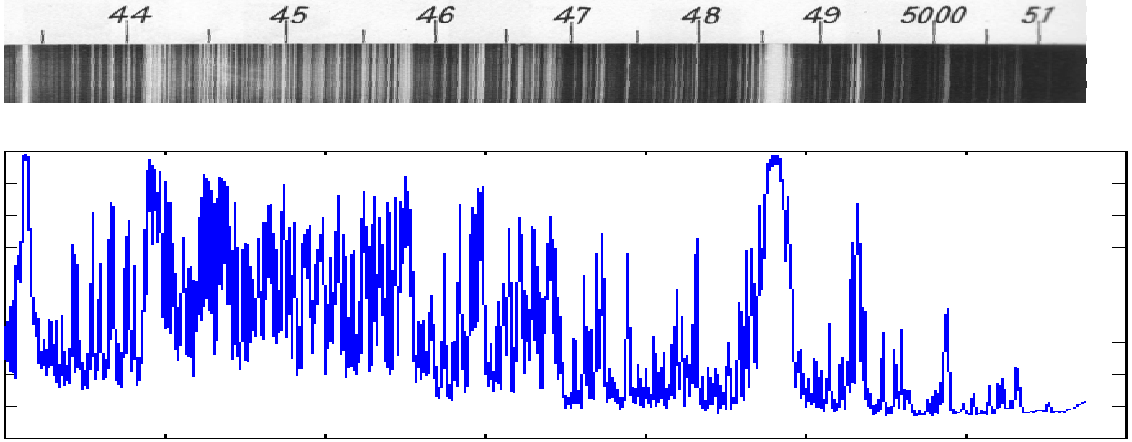
PLASMA OES DURING SiN ETCH



CH_2F_2 & CF_4 in Ar Etching Silicon

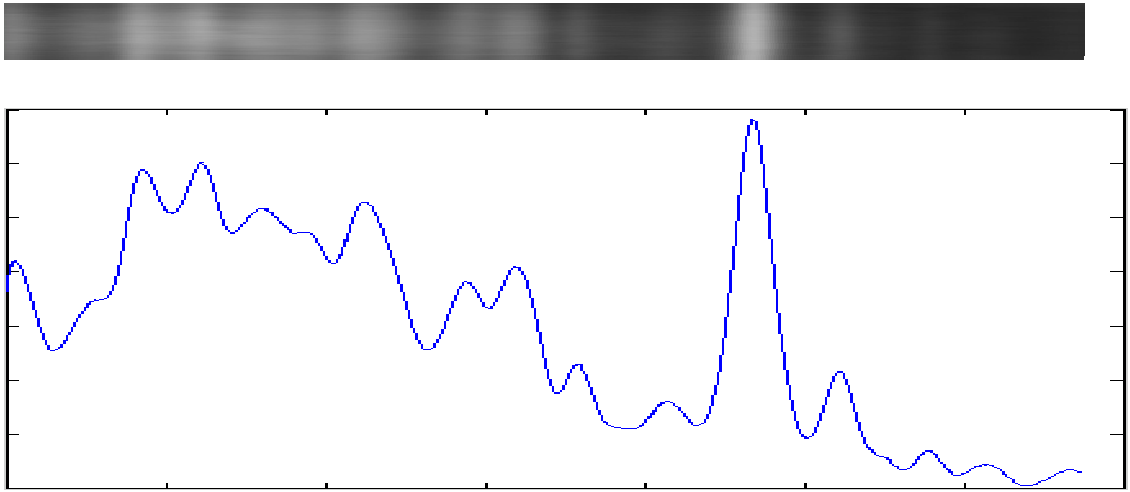


Spectrograph Resolution Effects on Spectra



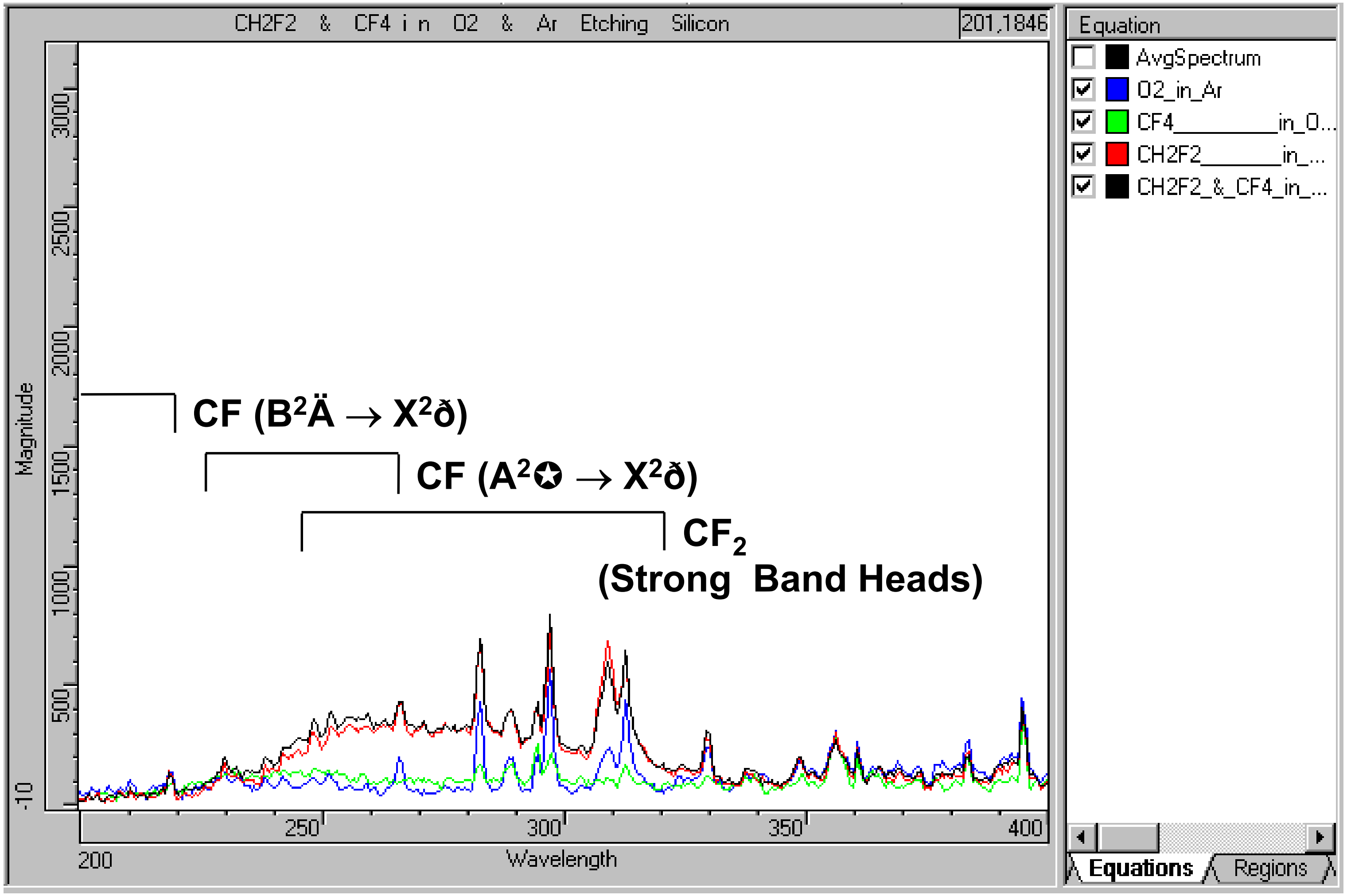
Extremely
High
Resolution *

* The Identification of Molecular Spectra, R.W.B. Pearse and A.G Gaydon, Halsted Press, 1976



Simulated
1.7 nm
Resolution

CH_2F_2 & CF_4 in O_2 & Ar Etching Silicon



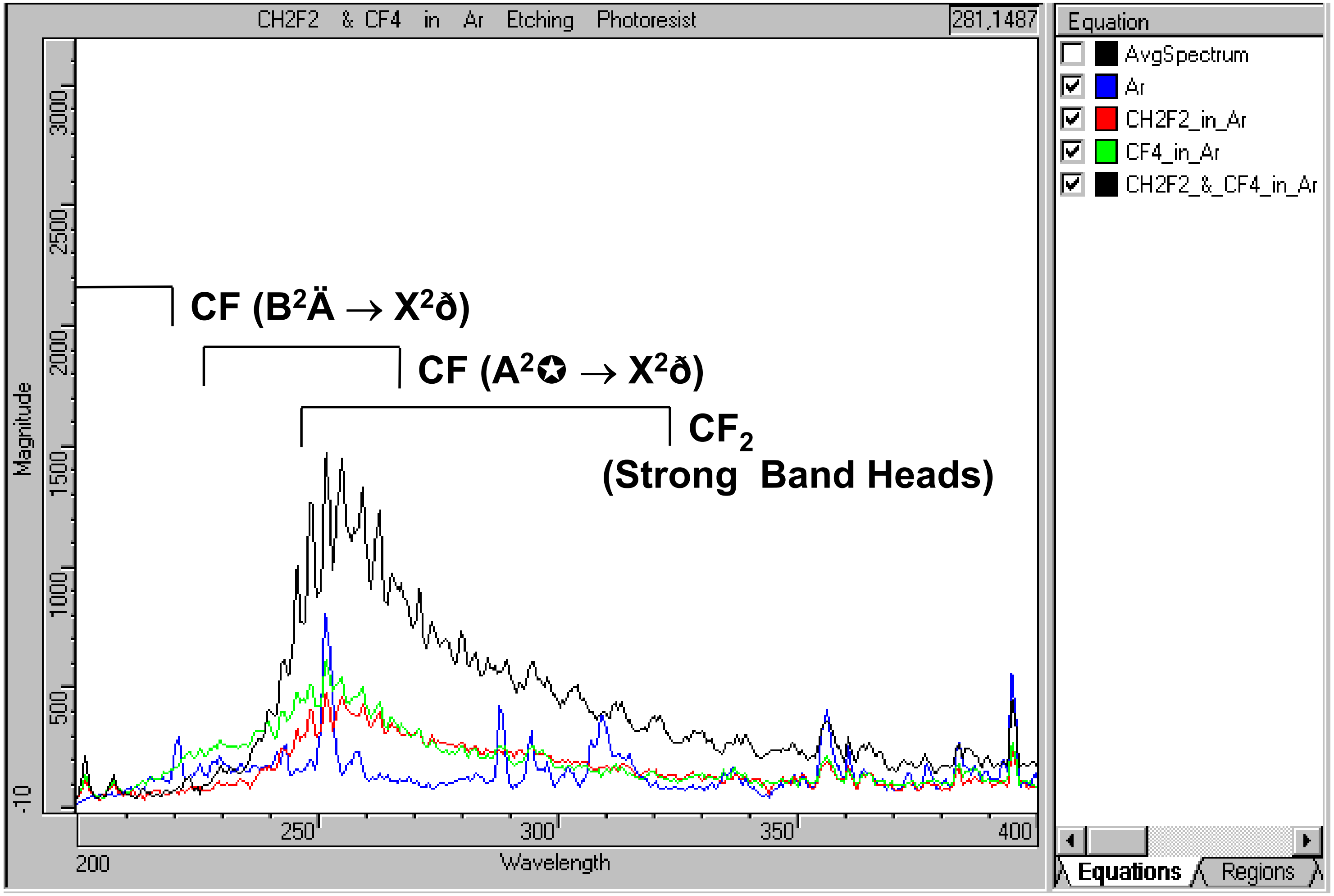
CF (B^{2}Ä → X^{2}ð)

CF (A^2✪ → X^{2}ð)

CF_2

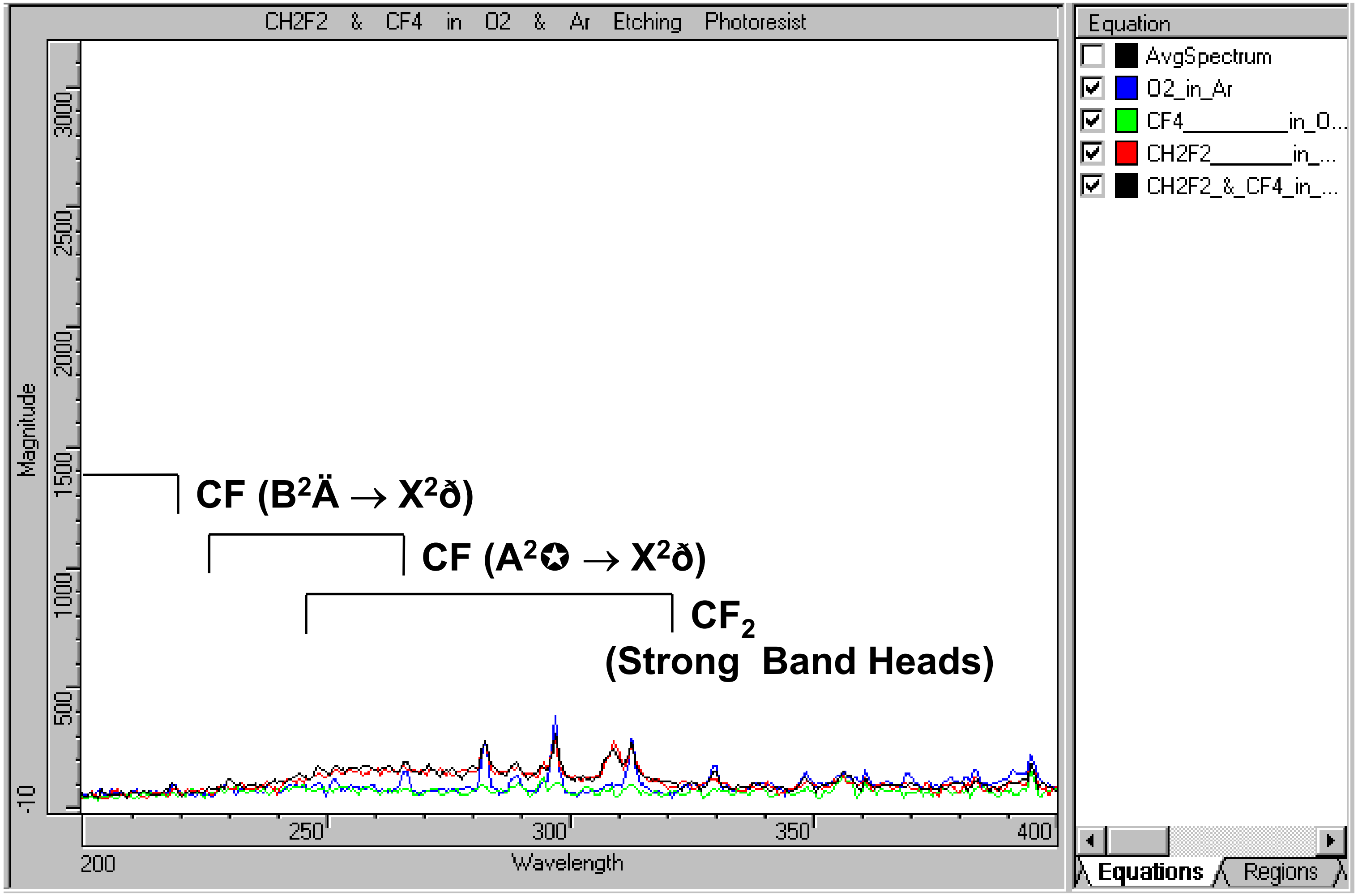
(Strong Band Heads)

CH$_2$F$_4$ & CF$_4$ in Ar Etching Photoresist



☐ ■ AvgSpectrum
☑ 🟦 Ar
☑ 🟥 CH2F2_in_Ar
☑ 🟩 CF4_in_Ar
☑ ■ CH2F2_&_CF4_in_Ar

CH_2F_2 & CF_4 in O_2 & Ar Etching Photoresist



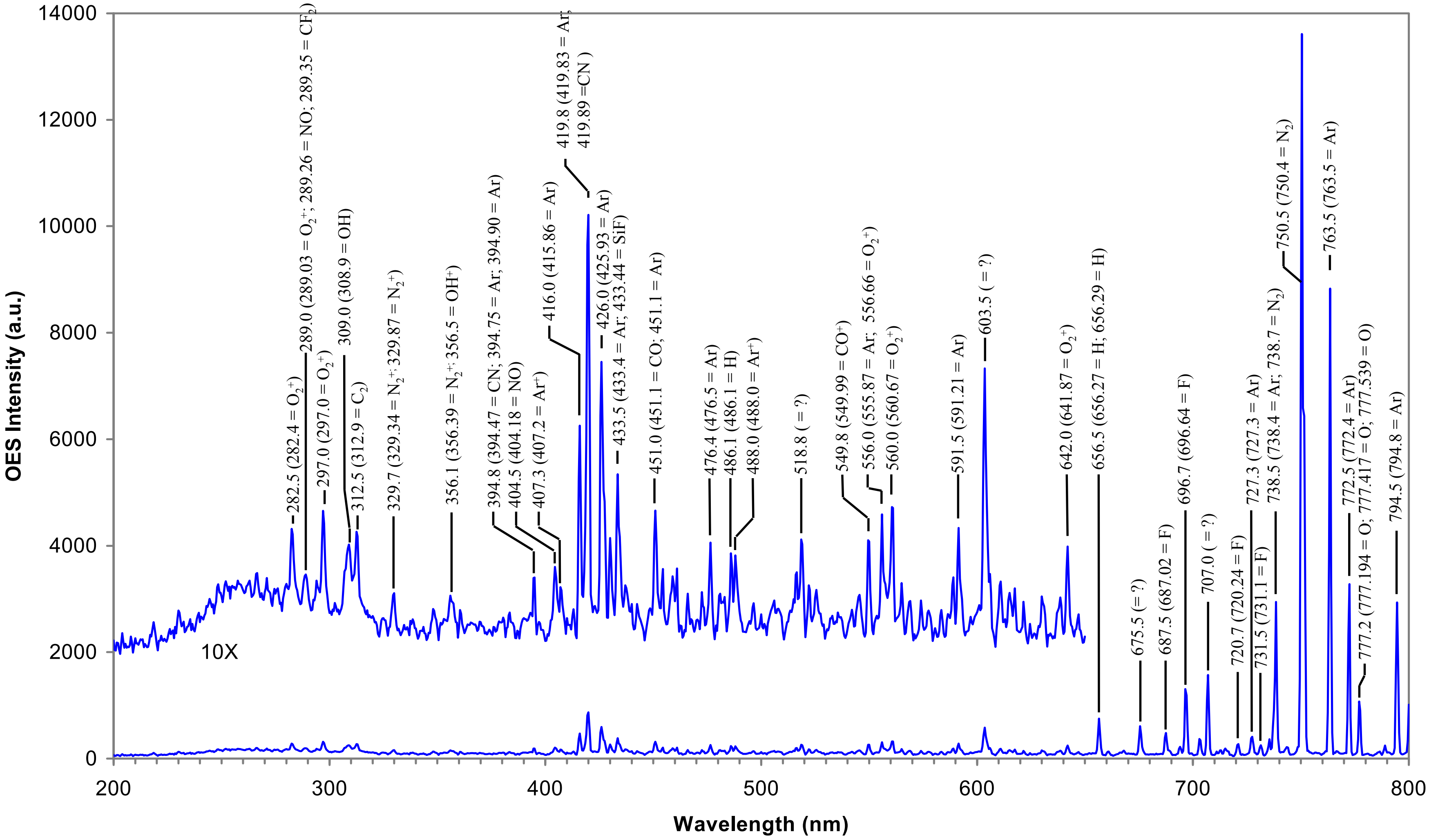
☐ ■ AvgSpectrum
☑ ■ O2_in_Ar
☑ ■ CF4__________in_O...
☑ ■ CH2F2________in_...
☑ ■ CH2F2_&_CF4_in_...

CF (B^{2}Ä → X^{2}ð)

CF (A^2✪ → X^{2}ð)

CF_2
(Strong Band Heads)

CH_2F_2 & CF_4 in O_2 & Ar Etching Photoresist



FG Celii & JW Hosch

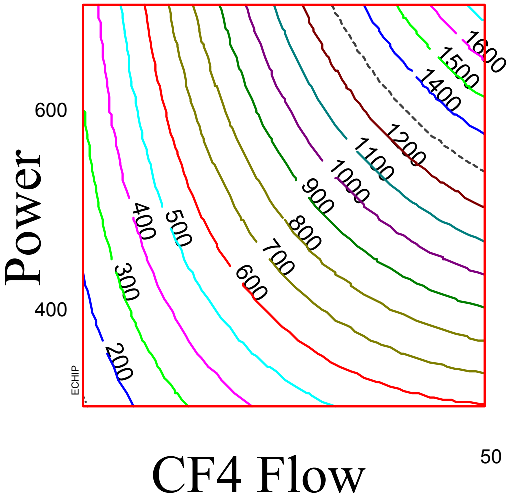
200-300 nm Emission Lines of Species that Change Concentration at Endpoint

WL	Species	Intensity	WL	Species	Intensity	WL	Species	Intensity	WL	Species	Intensity
201.18	CO	8	239.96	CF	9	253.23	O_2^+	6	276.12	CF_2	5
202.58	CO	9	240.22	SiF_3	10	253.92	SiF	7	276.19	O_2^+	7
204.63	CO	10	240.73	SiF_3	9	255.03	CO^+	7	277.42	CF_2	5
206.76	CO	10	240.76	CO	7	255.06	CF_2	8	278.05	SiO	7
208.893	Si	6	240.91	CO^+	6	255.07	N_2	8	278.54	CO	8
208.99	CO	10	241.38	SiO	7	255.79	NO	5	279.97	CO	9
210.72	CO	7	241.94	CO^+	8	255.82	CF	7	279.98	CF_2	8
211.24	CO^+	8	242.20	SiF_3	7	256.38	SiO	5	280.63	SiO	8
211.31	CO	9	242.74	SiF_3	10	257.77	CO^+	10	281.04	NO	5
212.412	Si	7	243.30	NO	7	258.10	O_2^+	8	281.13	OH	6
212.83	CO	8	243.39	CO	9	258.71	SiO	5	281.60	OH	6
213.78	CO^+	6	243.82	CO^+	9	259.50	CF_2	9	281.91	OH	6
215.02	CO	8	244.58	CO^+	10	259.51	SiF	5	282.37	O_2^+	8
215.49	NO	7	244.73	SiF_3	9	259.57	NO	9	282.90	OH	6
217.30	CO	9	244.80	N_2	10	260.72	CO^+	8	283.31	CO	10
218.98	CO^+	10	245.25	SiF_3	7	260.83	NO	6	285.25	CF_2	6
219.68	CO	10	245.76	CF_2	7	262.66	NO	6	285.5	C_2	10
222.15	CO	10	246.32	CO	10	262.85	CF_2	9	285.95	NO	7
223.61	NO	6	247.36	CO^+	10	263.00	CO	6	286.61	CF_2	6
223.83	CO	9	247.39	CF	8	263.27	O_2^+	6	288.158	Si	7
224.72	CO	7	247.42	CO^+	10	263.88	CO^+	8	288.18	CO_2^+	9
226.17	CO	9	247.857	C	10	265.24	CF_2	6	288.40	CO_2^+	9
226.94	NO	8	247.87	NO	10	266.05	N_2	5	289.03	O_2^+	7
228.61	CO	7	248.68	SiO	6	266.53	CO	8	289.26	NO	10
229.89	SiO	6	248.78	CF_2	9	266.90	SiO	9	289.35	CF_2	7
229.96	CO^+	10	248.83	O_2^+	6	267.24	CO^+	7	289.44	SiF	6
231.15	CO	8	249.29	CO	8	267.55	CF_2	6	289.51	CO_2^+	9
231.27	C_2	8	249.34	NO	7	268.00	NO	5	289.75	CO_2^+	9
232.52	CO^+	9	250.46	CO^+	10	268.81	CF_2	5	290.19	O_2^+	7
232.78	CF	10	250.690	Si	5	269.37	SiO	9	292.13	CF_2	6
233.79	CO	7	250.99	CO	8	269.83	CO	6	295.32	N_2	6
234.43	SiO	5	251.432	Si	4	270.53	O_2^+	7	296.20	N_2	6
235.14	N_2	6	251.611	Si	10	271.13	CF_2	9	296.7	C_2	10
235.25	CO^+	6	251.86	CF_2	9	272.22	NO	8	296.71	SiF	6
236.57	SiO	6	251.921	Si	3	272.23	CO^+	7	297.00	O_2^+	7
237.02	NO	10	252.412	Si	7	274.26	CO	6	297.68	N_2	6
238.16	CO	6	252.851	Si	6	274.91	CF_2	8	297.74	CO	9
238.27	SiF_3	7	252.97	CO^+	7	275.43	NO	9			
238.79	SiO	5	253.02	NH	9	275.50	SiO	6			

Blanket Etch Rate Results
DOE with Power, CF_4, Flow

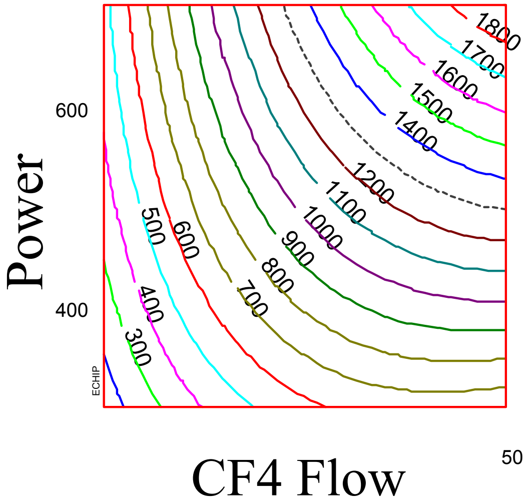
Lack Of Fit

NitrideER

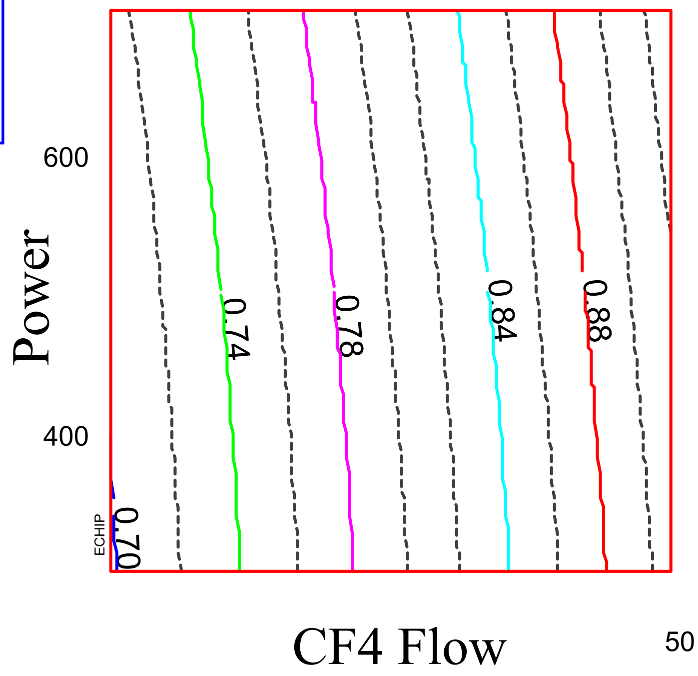


N_2/O_2 = 450/50
Pwr=300 W
Press=200 mT

OxideER

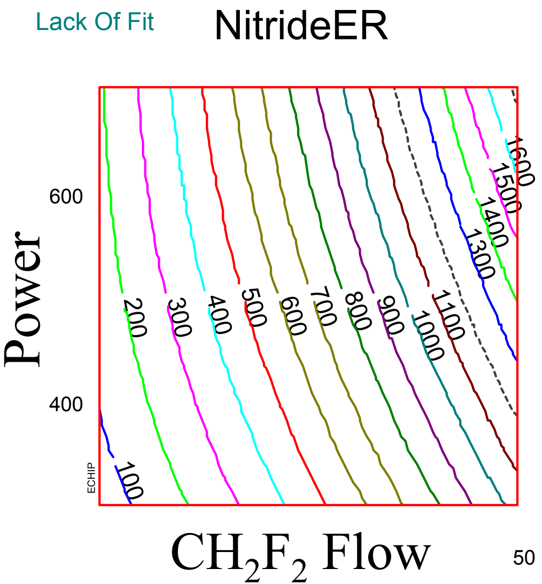


NitOxSelect

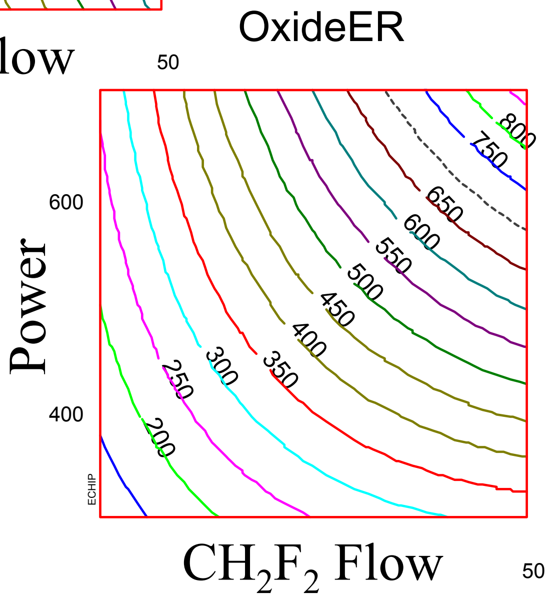


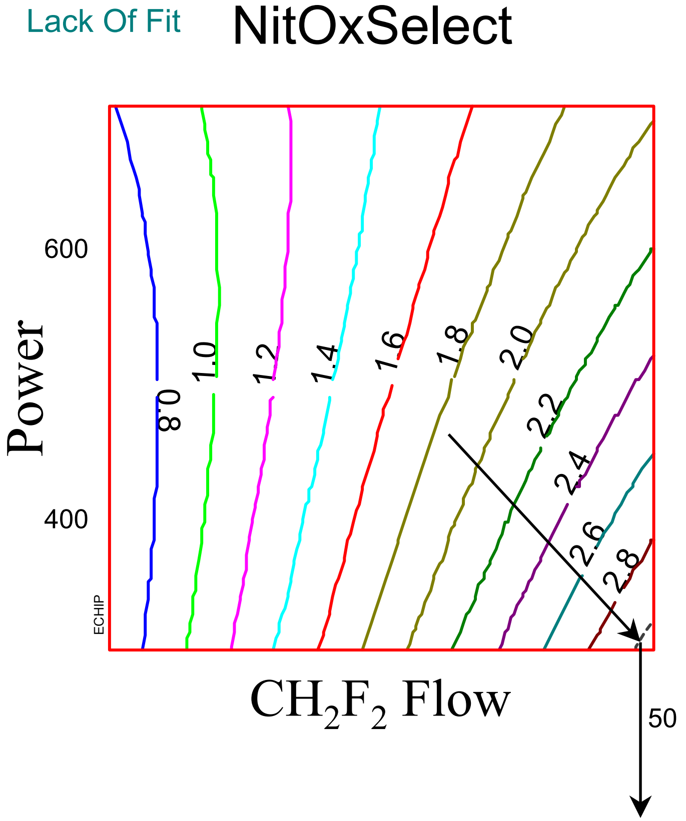
Blanket Etch Results

DOE with Power, CH_2F_2 Flow



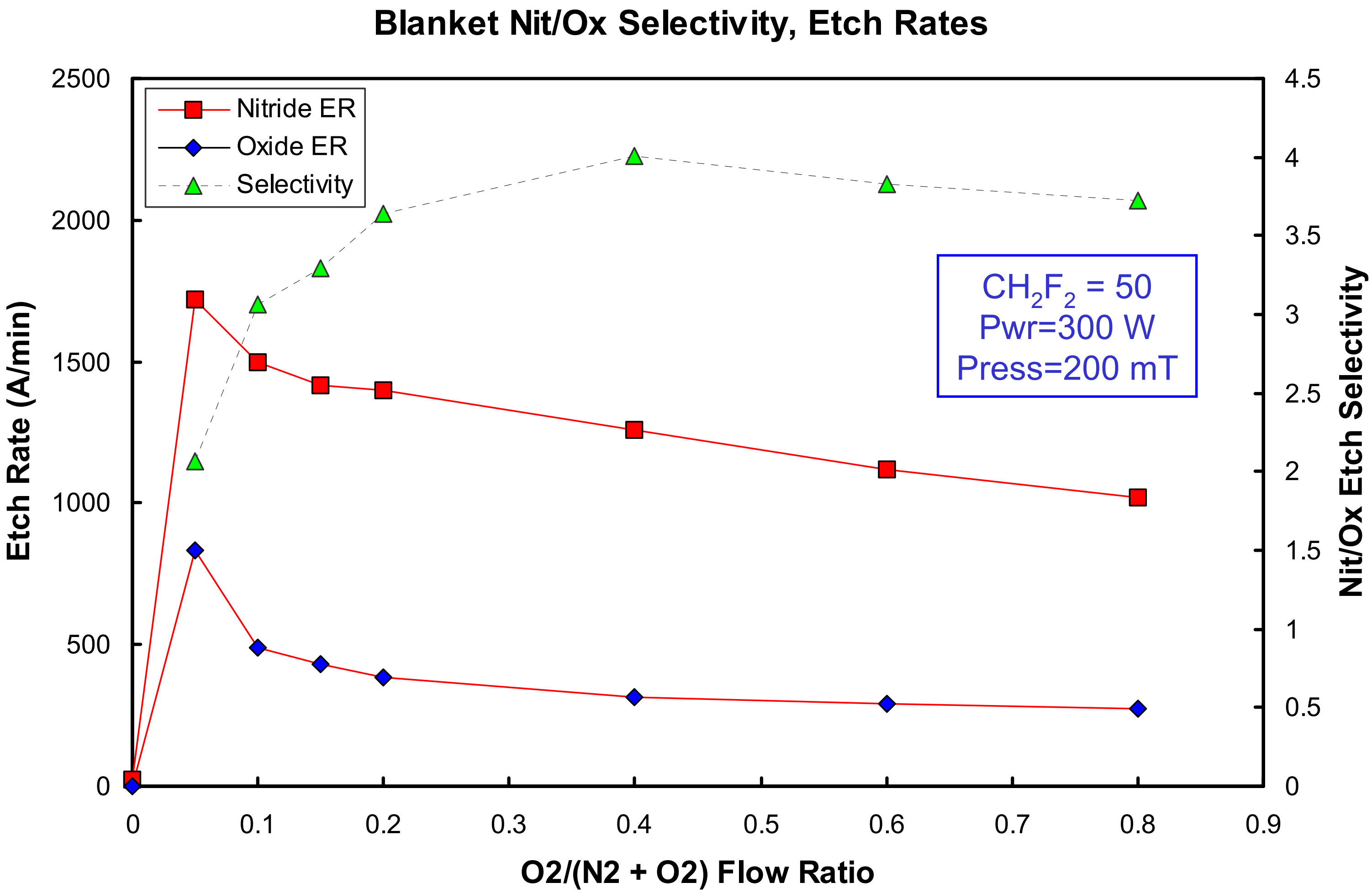
N_2/O_2 = 450/50
Pwr=300 W
Press=200 mT





Survey lower power

Blanket Etch Results: Survey of N_2/O_2 Flow

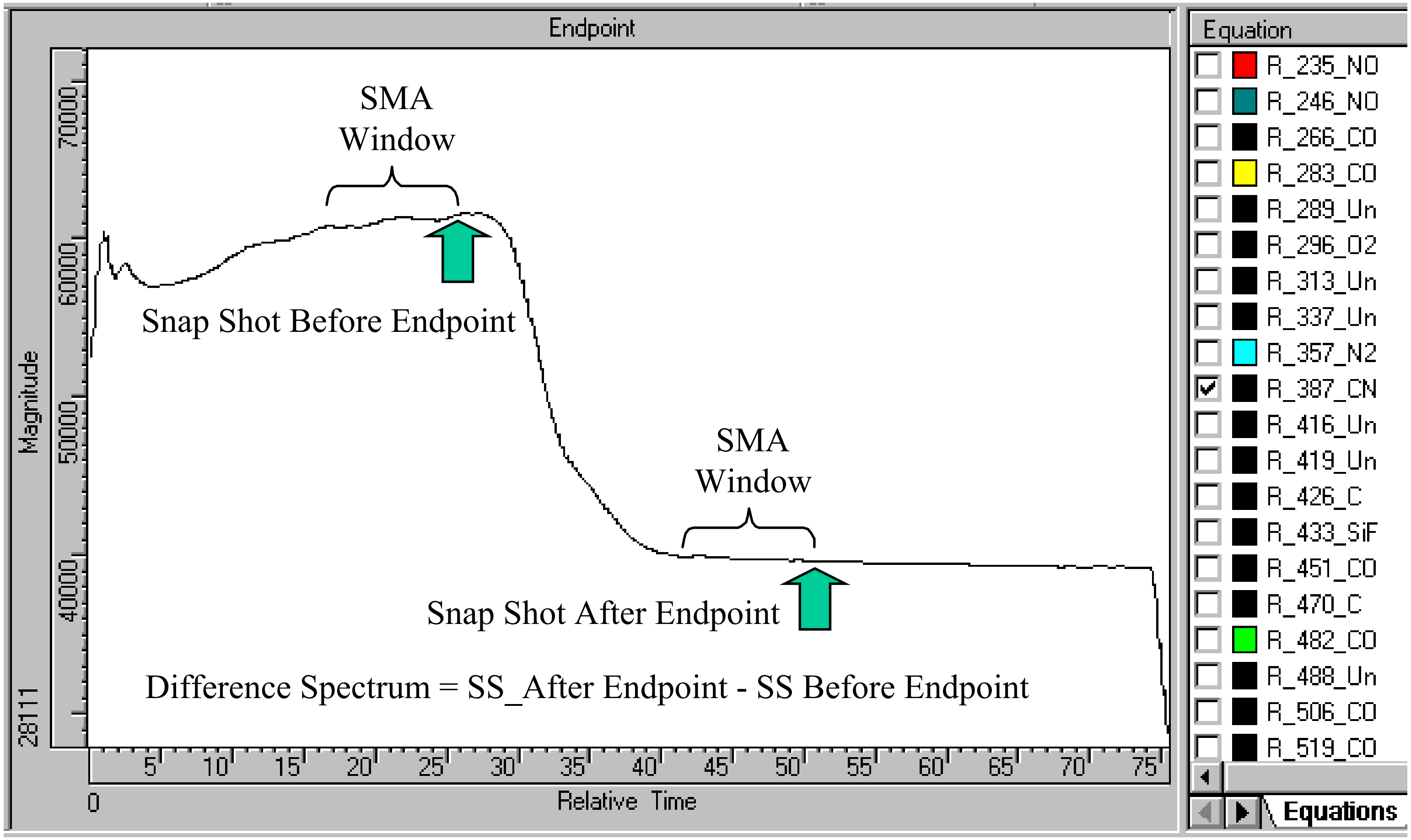


CH_2F_2 = 50
Pwr=300 W
Press=200 mT

Methods for Developing an Endpoint Detection Algorithm for a New Process

- The Plasma Process: Etch SiN stopping on silicide using CH_2F_2 in Ar with O_2
- Similar to other SiN etches
- Previous endpoint wavelength
  = 387 nm CN
- Difference Spectrum → Ratio of Wavelengths
- NeuralPCA Multivariate Method

387 nm Emission of CN from Etching a Blanket Film of SiN on Silicide



SMA Window

Snap Shot Before Endpoint

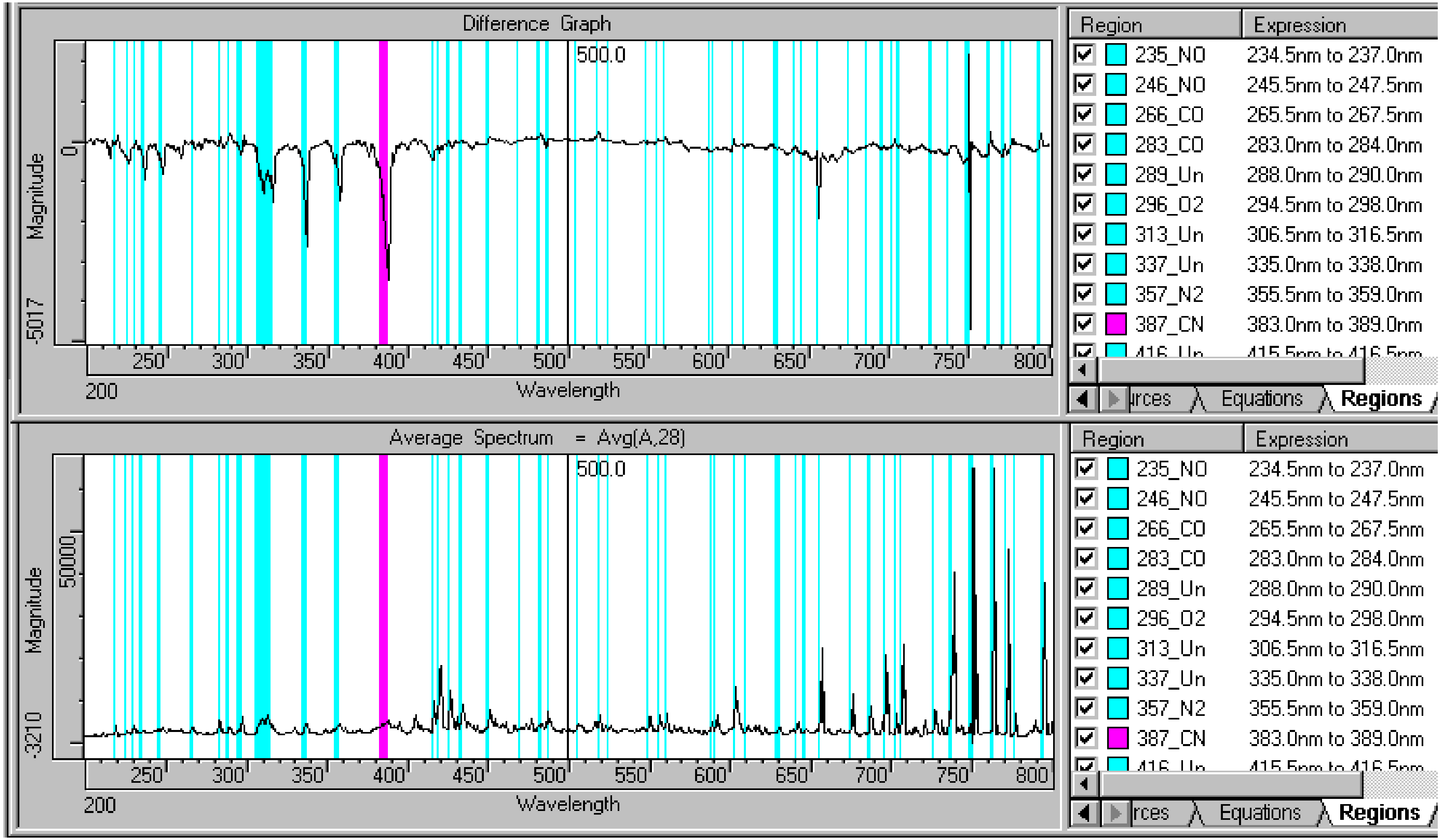
SMA Window

Snap Shot After Endpoint

Difference Spectrum = SS_After Endpoint - SS Before Endpoint

☐ 🟥 R_235_NO
☐ 🟦 R_246_NO
☐ ⬛ R_266_CO
☐ 🟨 R_283_CO
☐ ⬛ R_289_Un
☐ ⬛ R_296_O2
☐ ⬛ R_313_Un
☐ ⬛ R_337_Un
☐ 🟦 R_357_N2
☑ ⬛ R_387_CN
☐ ⬛ R_416_Un
☐ ⬛ R_419_Un
☐ ⬛ R_426_C
☐ ⬛ R_433_SiF
☐ ⬛ R_451_CO
☐ ⬛ R_470_C
☐ 🟩 R_482_CO
☐ ⬛ R_488_Un
☐ ⬛ R_506_CO
☐ ⬛ R_519_CO

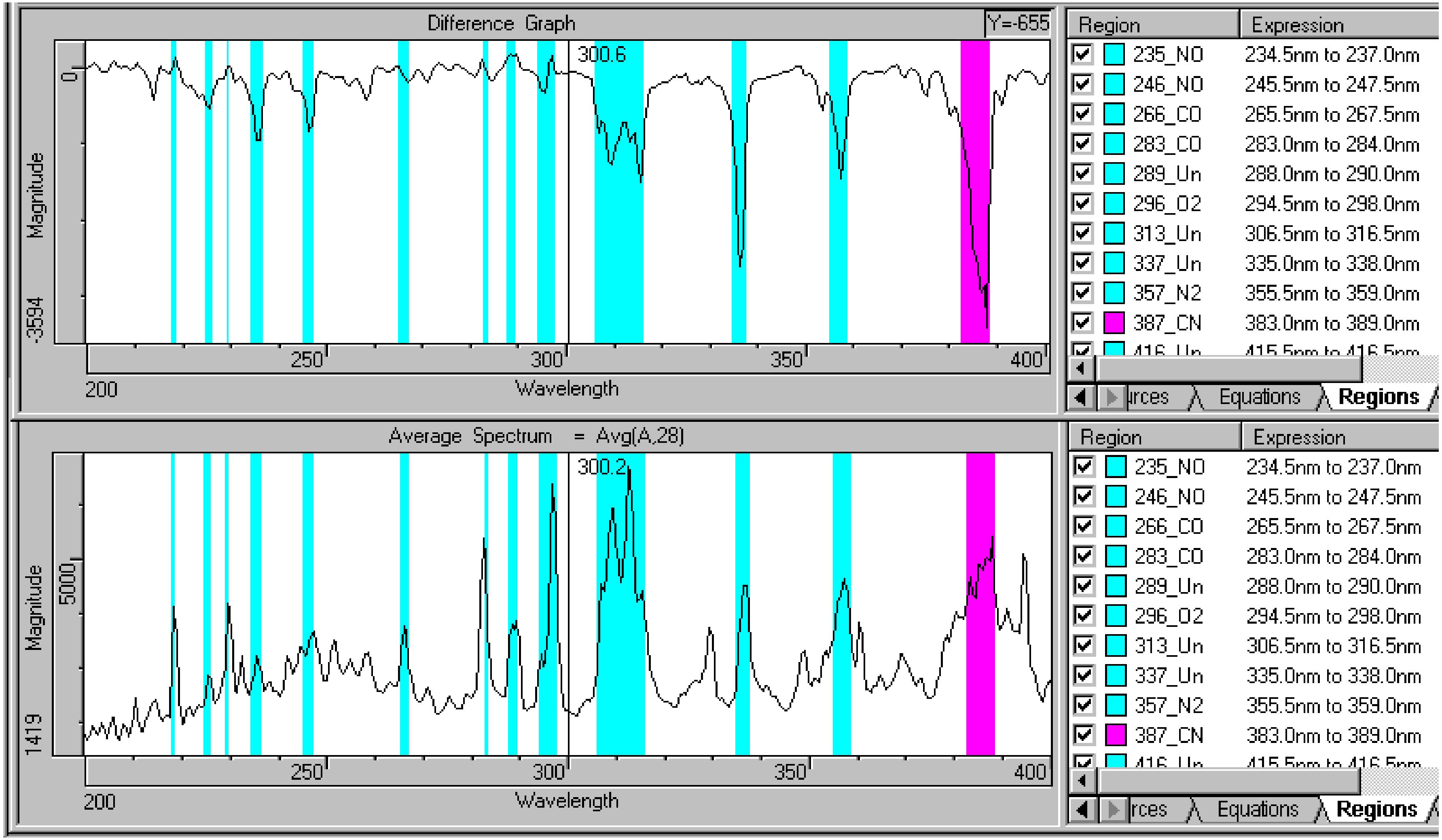
Regions Defined Using Difference Spectrum



		Region	Expression
☑	🟦	235_NO	234.5nm to 237.0nm
☑	🟦	246_NO	245.5nm to 247.5nm
☑	🟦	266_CO	265.5nm to 267.5nm
☑	🟦	283_CO	283.0nm to 284.0nm
☑	🟦	289_Un	288.0nm to 290.0nm
☑	🟦	296_O2	294.5nm to 298.0nm
☑	🟦	313_Un	306.5nm to 316.5nm
☑	🟦	337_Un	335.0nm to 338.0nm
☑	🟦	357_N2	355.5nm to 359.0nm
☑	🟪	387_CN	383.0nm to 389.0nm
☑	🟦	416_Un	415.5nm to 416.5nm

		Region	Expression
☑	🟦	235_NO	234.5nm to 237.0nm
☑	🟦	246_NO	245.5nm to 247.5nm
☑	🟦	266_CO	265.5nm to 267.5nm
☑	🟦	283_CO	283.0nm to 284.0nm
☑	🟦	289_Un	288.0nm to 290.0nm
☑	🟦	296_O2	294.5nm to 298.0nm
☑	🟦	313_Un	306.5nm to 316.5nm
☑	🟦	337_Un	335.0nm to 338.0nm
☑	🟦	357_N2	355.5nm to 359.0nm
☑	🟪	387_CN	383.0nm to 389.0nm
☑	🟦	416_Un	415.5nm to 416.5nm

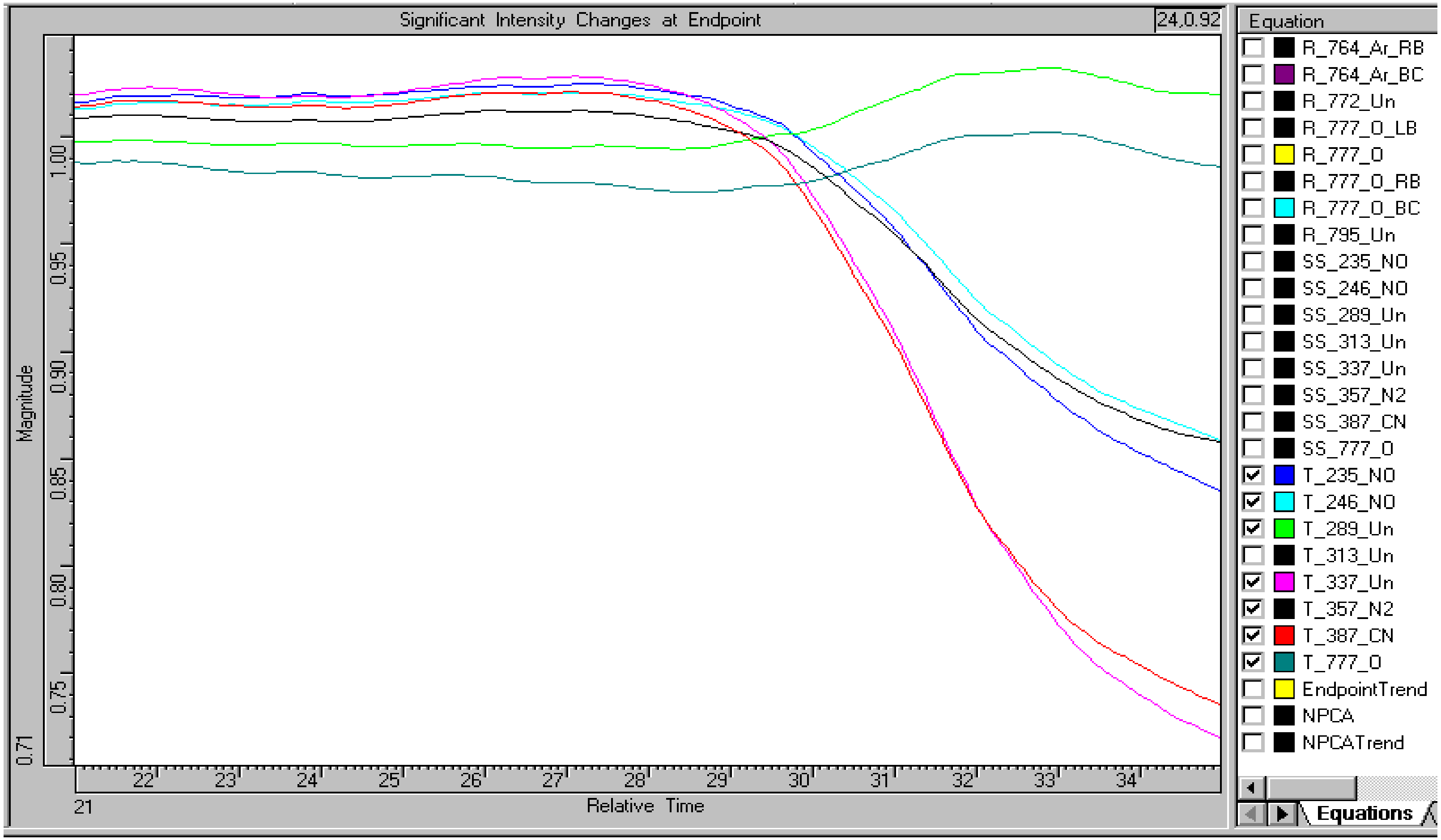
Expanded View of Regions



Region	Expression
☑ 🟦 235_NO	234.5nm to 237.0nm
☑ 🟦 246_NO	245.5nm to 247.5nm
☑ 🟦 266_CO	265.5nm to 267.5nm
☑ 🟦 283_CO	283.0nm to 284.0nm
☑ 🟦 289_Un	288.0nm to 290.0nm
☑ 🟦 296_O2	294.5nm to 298.0nm
☑ 🟦 313_Un	306.5nm to 316.5nm
☑ 🟦 337_Un	335.0nm to 338.0nm
☑ 🟦 357_N2	355.5nm to 359.0nm
☑ 🟪 387_CN	383.0nm to 389.0nm
☑ 🟦 416_Un	415.5nm to 416.5nm

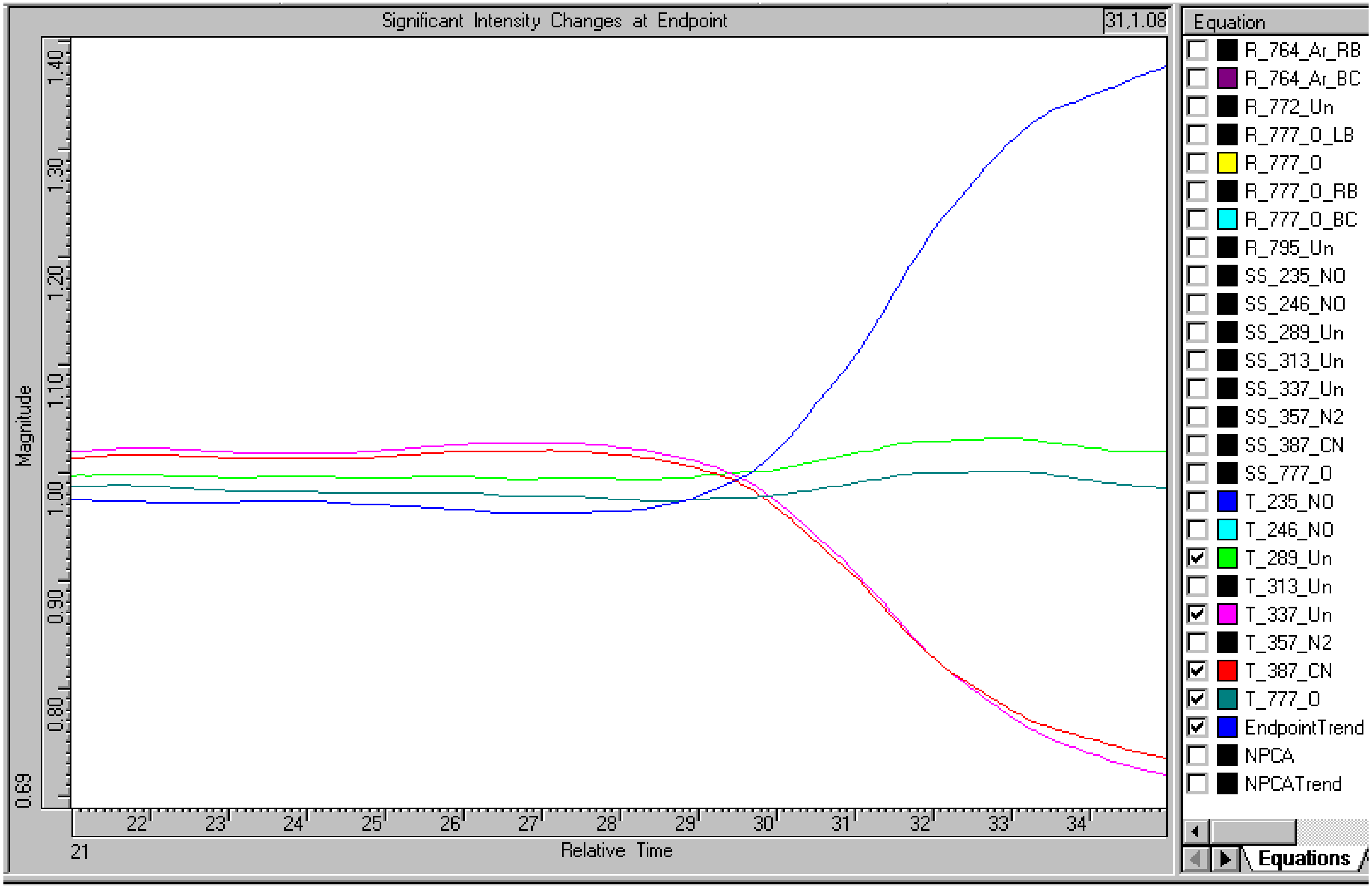
Region	Expression
☑ 🟦 235_NO	234.5nm to 237.0nm
☑ 🟦 246_NO	245.5nm to 247.5nm
☑ 🟦 266_CO	265.5nm to 267.5nm
☑ 🟦 283_CO	283.0nm to 284.0nm
☑ 🟦 289_Un	288.0nm to 290.0nm
☑ 🟦 296_O2	294.5nm to 298.0nm
☑ 🟦 313_Un	306.5nm to 316.5nm
☑ 🟦 337_Un	335.0nm to 338.0nm
☑ 🟦 357_N2	355.5nm to 359.0nm
☑ 🟪 387_CN	383.0nm to 389.0nm
☑ 🟦 416_Un	415.5nm to 416.5nm

Dominant Normalized Intensity Changes at Endpoint



- ☐ R_764_Ar_RB
- ☐ R_764_Ar_BC
- ☐ R_772_Un
- ☐ R_777_O_LB
- ☐ R_777_O
- ☐ R_777_O_RB
- ☐ R_777_O_BC
- ☐ R_795_Un
- ☐ SS_235_NO
- ☐ SS_246_NO
- ☐ SS_289_Un
- ☐ SS_313_Un
- ☐ SS_337_Un
- ☐ SS_357_N2
- ☐ SS_387_CN
- ☐ SS_777_O
- ☑ T_235_NO
- ☑ T_246_NO
- ☑ T_289_Un
- ☐ T_313_Un
- ☑ T_337_Un
- ☑ T_357_N2
- ☑ T_387_CN
- ☑ T_777_O
- ☐ EndpointTrend
- ☐ NPCA
- ☐ NPCATrend

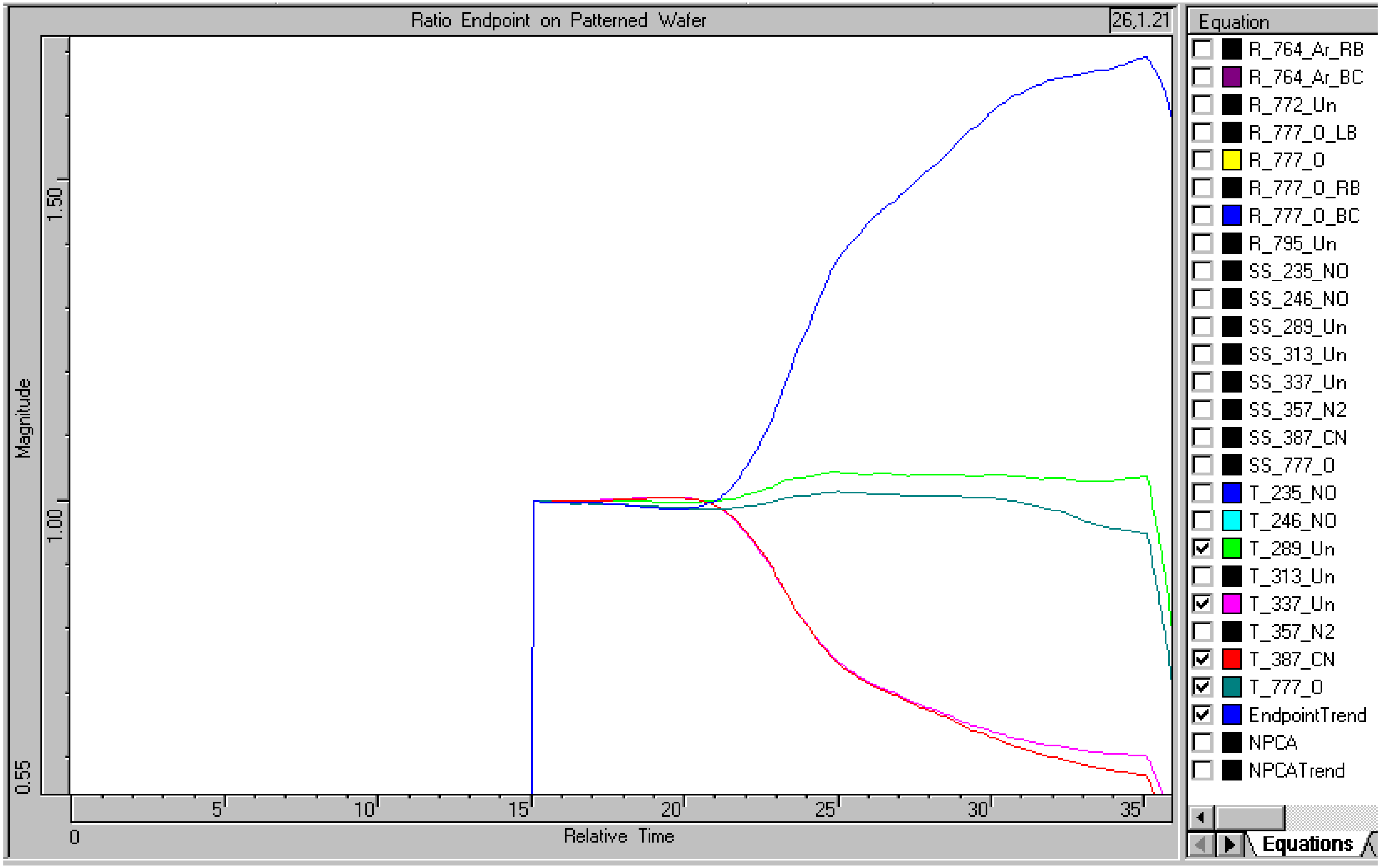
Ratio Endpoint on Wafer Without Resist



Equation

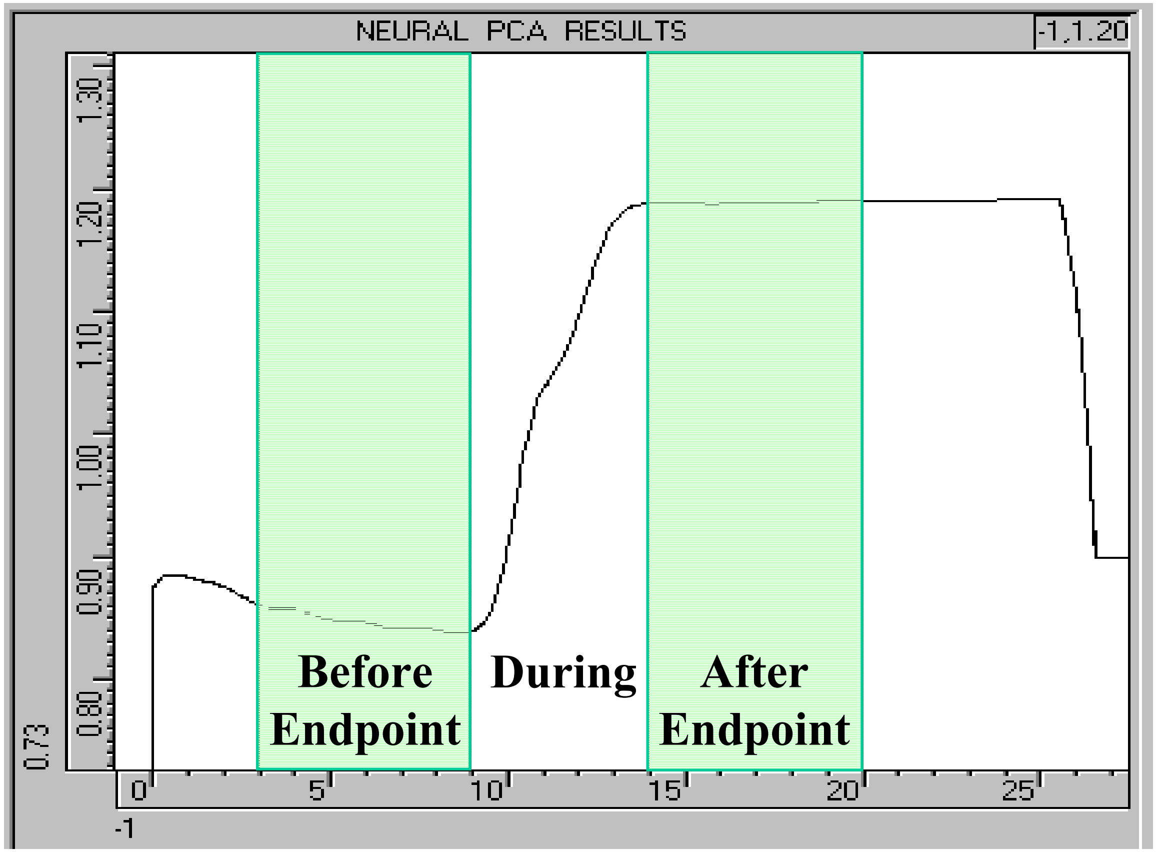
- ☐ ⬛ R_764_Ar_RB
- ☐ 🟪 R_764_Ar_BC
- ☐ ⬛ R_772_Un
- ☐ ⬛ R_777_O_LB
- ☐ 🟨 R_777_O
- ☐ ⬛ R_777_O_RB
- ☐ 🟦 R_777_O_BC
- ☐ ⬛ R_795_Un
- ☐ ⬛ SS_235_NO
- ☐ ⬛ SS_246_NO
- ☐ ⬛ SS_289_Un
- ☐ ⬛ SS_313_Un
- ☐ ⬛ SS_337_Un
- ☐ ⬛ SS_357_N2
- ☐ ⬛ SS_387_CN
- ☐ ⬛ SS_777_O
- ☐ 🟦 T_235_NO
- ☐ 🟦 T_246_NO
- ☑ 🟩 T_289_Un
- ☐ ⬛ T_313_Un
- ☑ 🟪 T_337_Un
- ☐ ⬛ T_357_N2
- ☑ 🟥 T_387_CN
- ☑ 🟩 T_777_O
- ☑ 🟦 EndpointTrend
- ☐ ⬛ NPCA
- ☐ ⬛ NPCATrend

Ratio Endpoint on Patterned Wafer



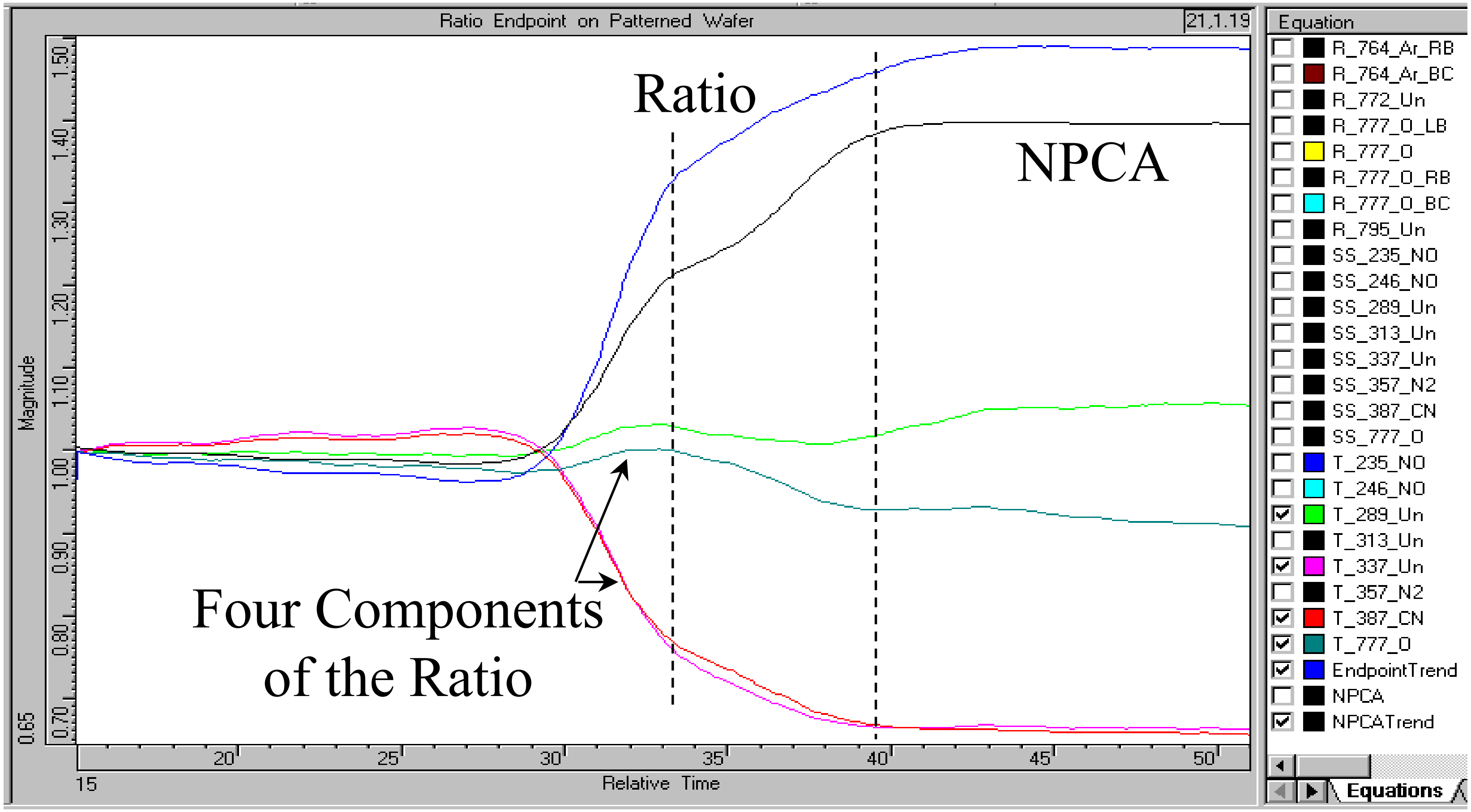
- ☐ ⬛ R_764_Ar_RB
- ☐ 🟪 R_764_Ar_BC
- ☐ ⬛ R_772_Un
- ☐ ⬛ R_777_O_LB
- ☐ 🟨 R_777_O
- ☐ ⬛ R_777_O_RB
- ☐ 🟦 R_777_O_BC
- ☐ ⬛ R_795_Un
- ☐ ⬛ SS_235_NO
- ☐ ⬛ SS_246_NO
- ☐ ⬛ SS_289_Un
- ☐ ⬛ SS_313_Un
- ☐ ⬛ SS_337_Un
- ☐ ⬛ SS_357_N2
- ☐ ⬛ SS_387_CN
- ☐ ⬛ SS_777_O
- ☐ 🟦 T_235_NO
- ☐ 🟦 T_246_NO
- ☑ 🟩 T_289_Un
- ☐ ⬛ T_313_Un
- ☑ 🟪 T_337_Un
- ☐ ⬛ T_357_N2
- ☑ 🟥 T_387_CN
- ☑ 🟩 T_777_O
- ☑ 🟦 EndpointTrend
- ☐ ⬛ NPCA
- ☐ ⬛ NPCATrend

First NPCA Calibration



Magnet Periods →

Results of First NPCA Calibration Used on the Calibration Wafer



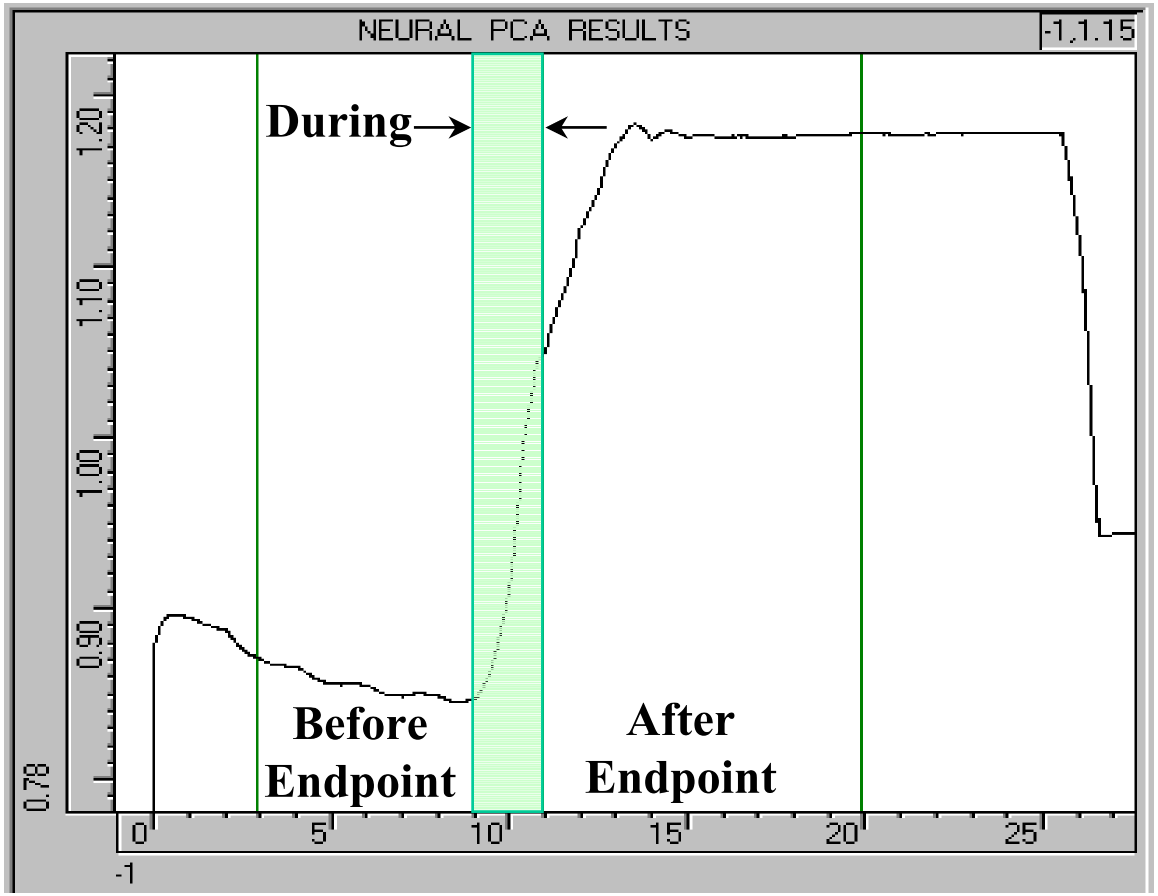
Ratio

NPCA

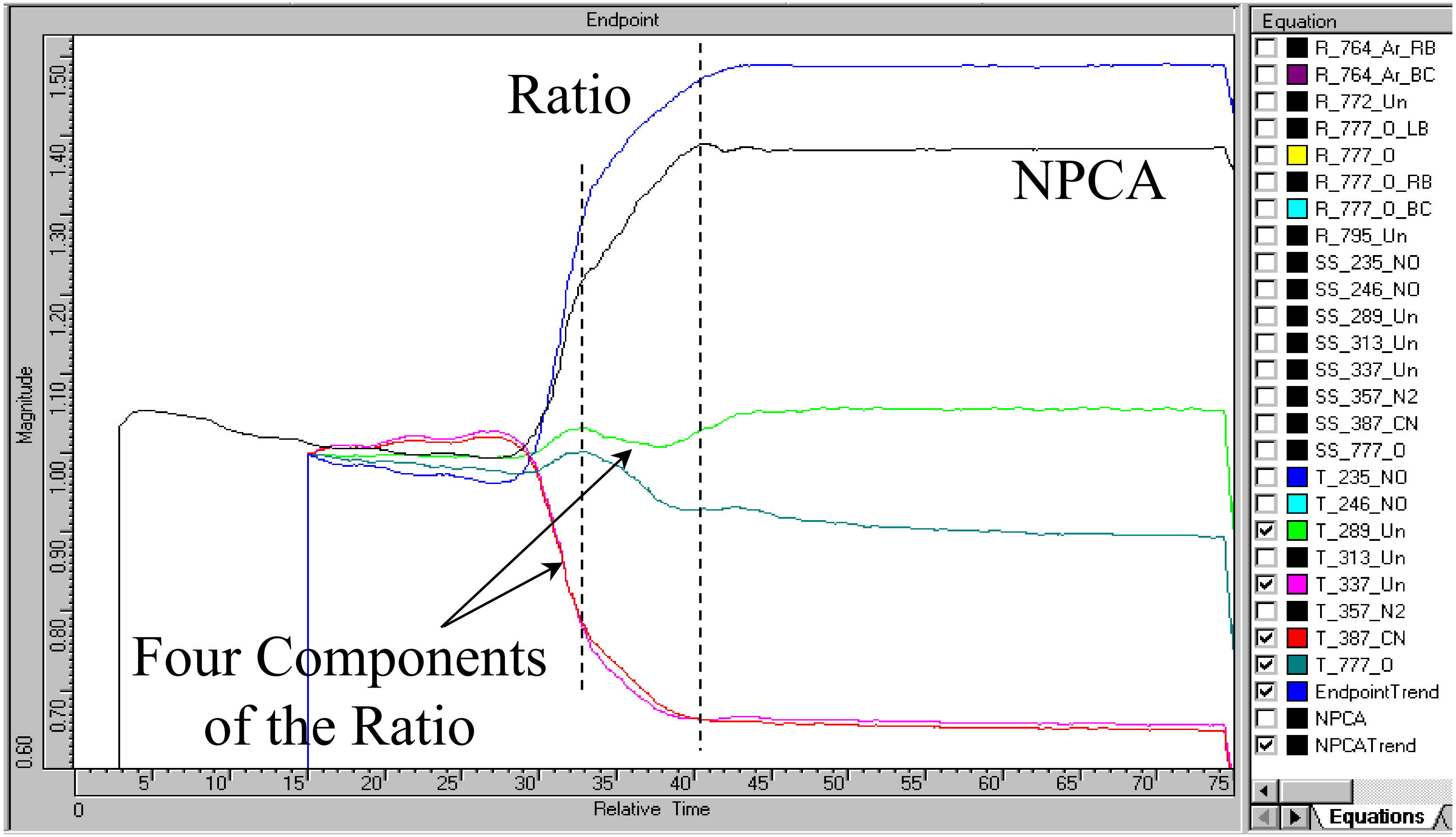
Four Components of the Ratio

☐ R_764_Ar_RB
☐ R_764_Ar_BC
☐ R_772_Un
☐ R_777_O_LB
☐ R_777_O
☐ R_777_O_RB
☐ R_777_O_BC
☐ R_795_Un
☐ SS_235_NO
☐ SS_246_NO
☐ SS_289_Un
☐ SS_313_Un
☐ SS_337_Un
☐ SS_357_N2
☐ SS_387_CN
☐ SS_777_O
☐ T_235_NO
☐ T_246_NO
☑ T_289_Un
☐ T_313_Un
☑ T_337_Un
☐ T_357_N2
☑ T_387_CN
☑ T_777_O
☑ EndpointTrend
☐ NPCA
☑ NPCATrend

Second NPCA Calibration



Results Second NPCA Calibration Used on the Calibration Wafer

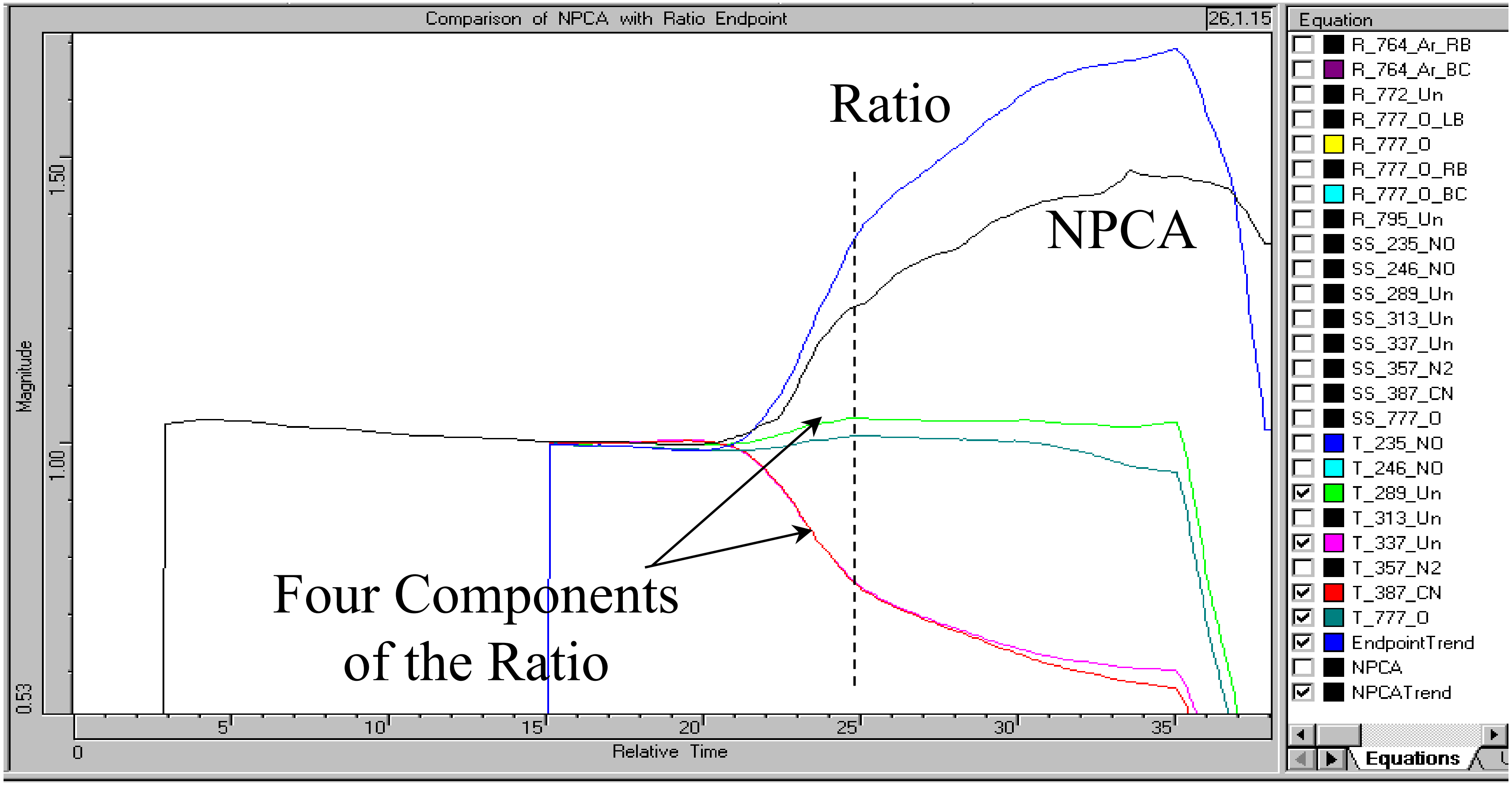


Ratio

NPCA

Four Components
of the Ratio

Comparison NPCA Calibration v.s. Ratio Endpoint Etching a Patterned Wafer



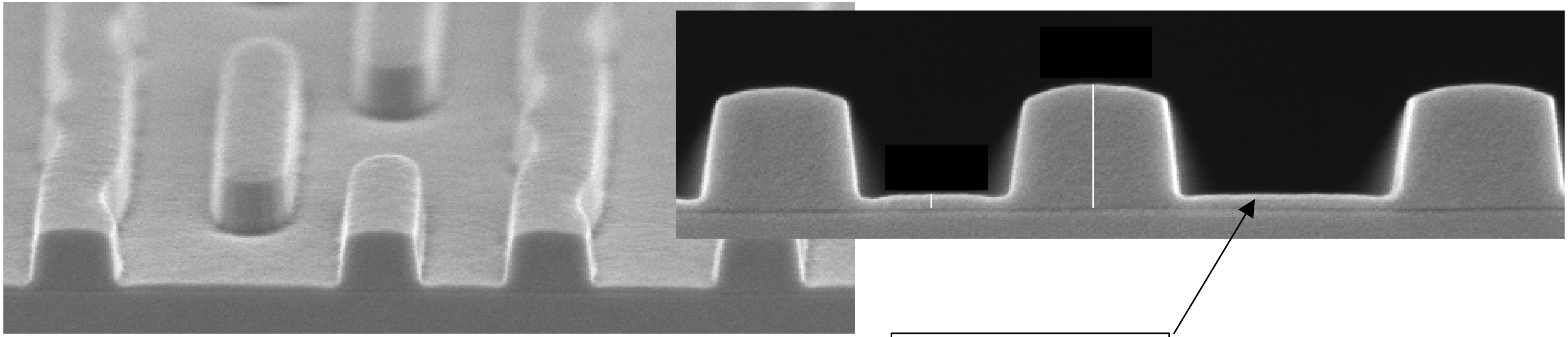
Equation
- ☐ ⬛ R_764_Ar_RB
- ☐ 🟪 R_764_Ar_BC
- ☐ ⬛ R_772_Un
- ☐ ⬛ R_777_O_LB
- ☐ 🟨 R_777_O
- ☐ ⬛ R_777_O_RB
- ☐ 🟦 R_777_O_BC
- ☐ ⬛ R_795_Un
- ☐ ⬛ SS_235_NO
- ☐ ⬛ SS_246_NO
- ☐ ⬛ SS_289_Un
- ☐ ⬛ SS_313_Un
- ☐ ⬛ SS_337_Un
- ☐ ⬛ SS_357_N2
- ☐ ⬛ SS_387_CN
- ☐ ⬛ SS_777_O
- ☐ 🟦 T_235_NO
- ☐ 🟦 T_246_NO
- ☑ 🟩 T_289_Un
- ☐ ⬛ T_313_Un
- ☑ 🟪 T_337_Un
- ☐ ⬛ T_357_N2
- ☑ 🟥 T_387_CN
- ☑ 🟦 T_777_O
- ☑ 🟦 EndpointTrend
- ☐ ⬛ NPCA
- ☑ ⬛ NPCATrend

ENDPOINTED ETCH RESULTS

x-SEM OF PATTERNED WAFERS

39.5 s etch

SRAM, center

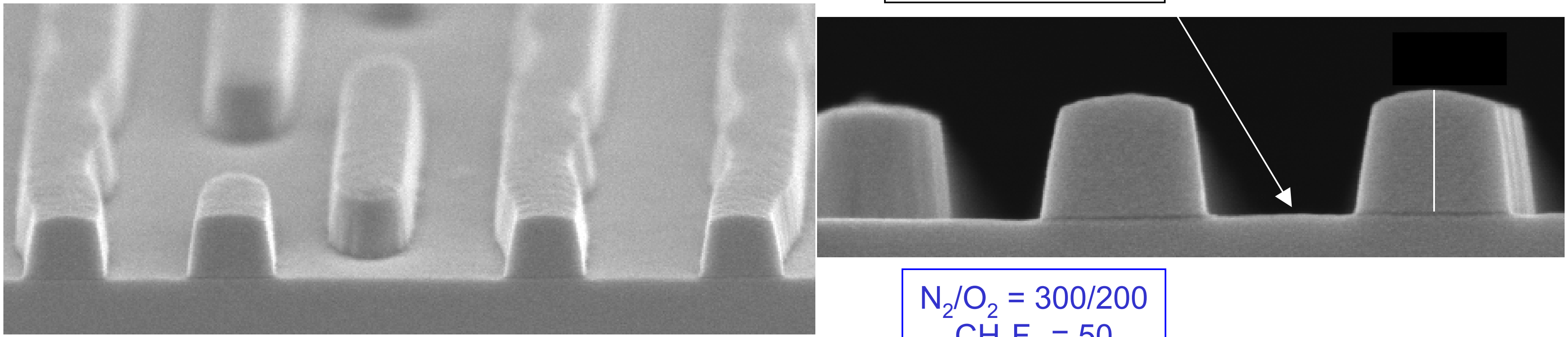


[redacted]

[redacted]

Center not clear,
Edge has cleared

SRAM, edge



[redacted]

N_2/O_2 = 300/200
CH_2F_2 = 50
300 W, 200 mT

Conclusions

- N_2 and O_2 in Ar with CH_2F_2 do enhance the SiN etch rate.
- Flow ratios for maximum etch rate and maximum selectivity.
- Overlapping spectral lines may adversely affect tracking NO concentration using actinometry. More work is required.
- The NeuralPCA multivariate endpoint technique can accommodate unresolved spectra from closely spaced emission lines.
- NPCA is easier to implement than selected wavelength endpoint techniques.
- Anticipate NPCA endpoint sensitivity similar to SiO_2 contact etch.