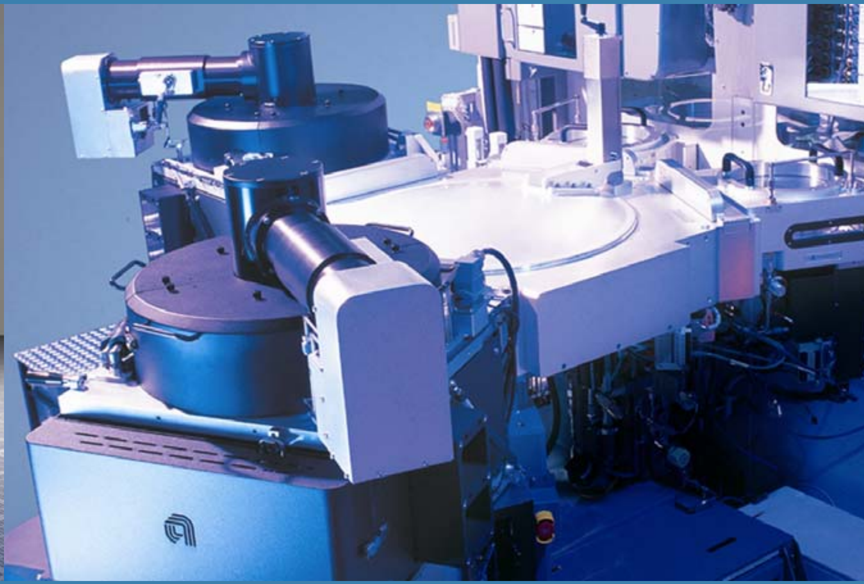


Effects of Dual Bias Frequency on SiO2 Contact Hole Etching in Very High Frequency Fluorocarbon Plasmas

Wonseok Lee, Shawming Ma, Jang Gyoo Yang,
Daniel Hoffman and Yan Ye

Dielectric Etch
Applied Materials
PEUG Meeting, Mar 10, 2005

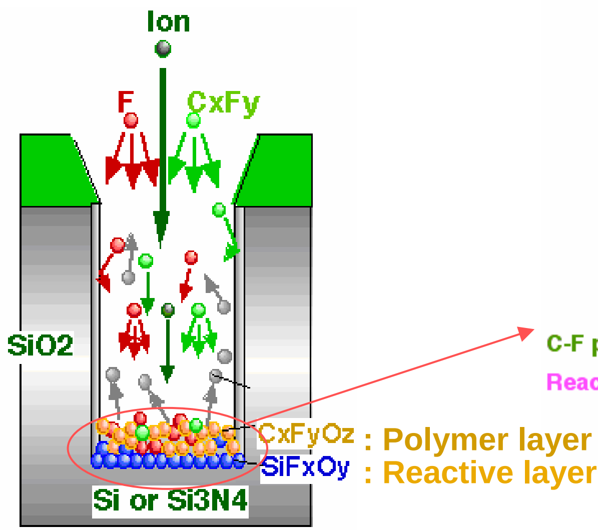
Outline

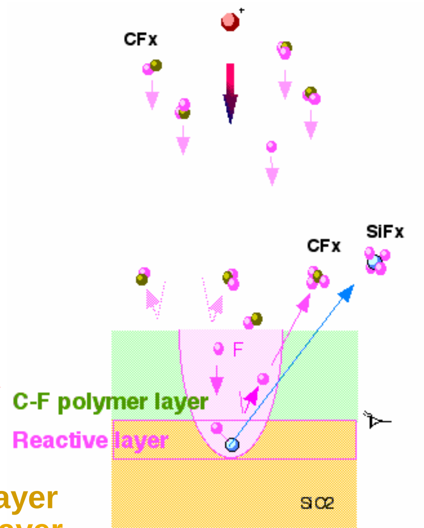
- Requirement of High Aspect Ratio (HAR) contact etch
  - Polymer deposition and ion energy distribution
- Dual bias effect on ion energy distribution
  - Bias frequency selection
  - Simulation of ion energy distribution
- Process results of high frequency source/dual bias chamber
  - Profile control
  - Process window
- Conclusion

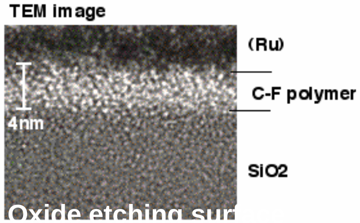
Why High Ion Energy Necessary for HARC?

Typical requirements for advanced HAR etching process

- Highly selective process (to mask and sub-layer) : thick polymer generation
- vertical profile is necessary : need easy penetration of reactive ion through polymer layer







Etch rate depends on

- Incident fluxes
  F, CF, CF_2, and CF_3 radical
- Surface reaction probability
  Incident ion energy
  Energy loss at the C-F polymer

2000 AVS, ASET

High selectivity ⇨ Thick polymer deposition over the reactive layer ⇨ Decreases net ion energy penetrating through polymer layer ⇨ low etch rate & tapered profile

High aspect ratio ⇨ Ion energy decreases at the bottom of hole due to ion scattering and shading effect from hole entrance ⇨ low etch rate & tapered profile

High incident Ei is necessary for high etch rate and vertical profile in HAR

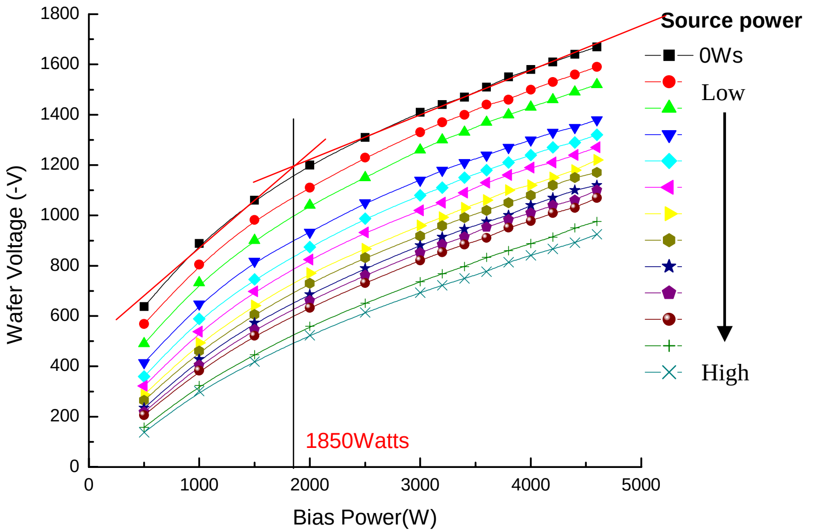
ENABLER

WS Lee
APPLIED MATERIALS

Vrf Behavior with VHF and 13.56MHz Bias

- Measuring tool : z-scan(z-Ware)
- Wafer type : Si dummy wafer
- Measuring plasma condition : HARC etching condition with PET process
  - Measuring V_{rf} at 10sec processing time

Measuring plasma condition : HARC etching condition with PET process



The efficiency of V_{rf} rise with bias power starts to get gentle over reasonable source and bias powers

Candidates for Increasing Ion Energy

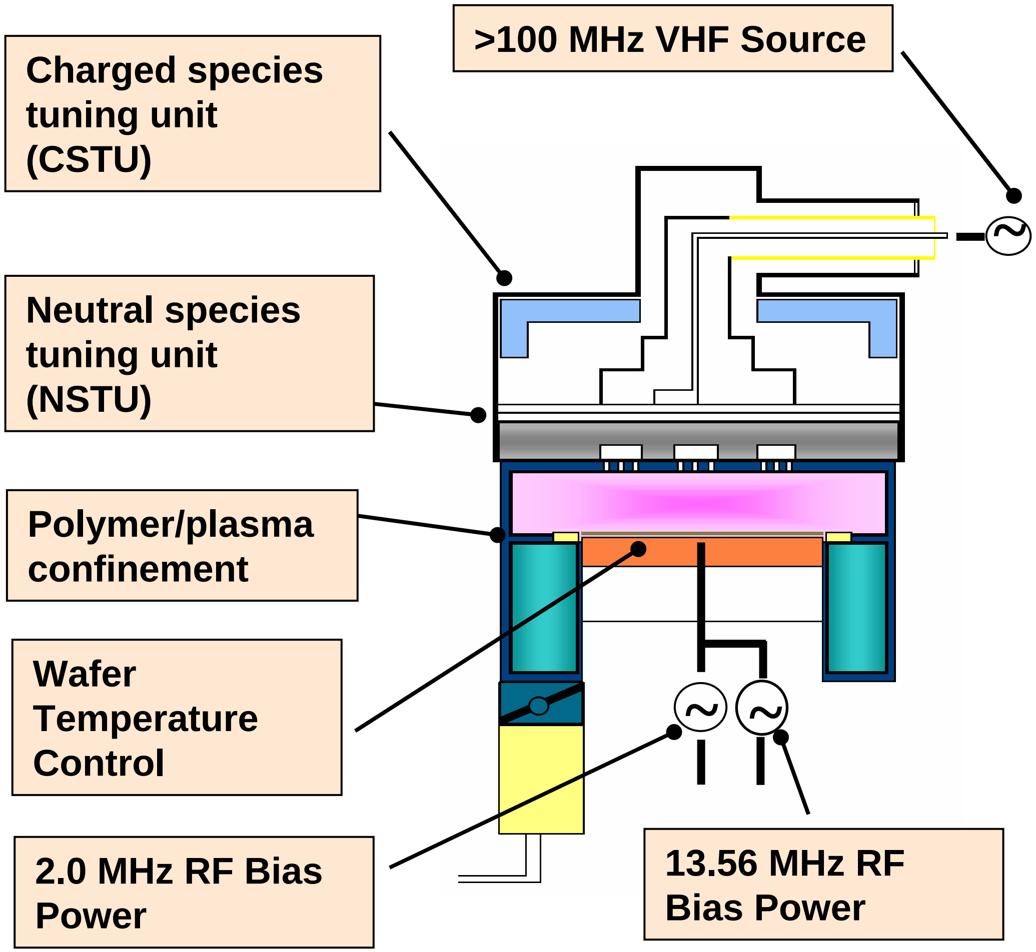
- Increase the ratio of Area_ground/Area_powered cathode
: Asymmetric sheath-> area ratio improvements already obtained.

- Increase RF bias generator capacity and try higher bias power
: V_{rf} can only increase 1.4X with 2 X power increase
Some customers restrict available maximum power.
Match box and ESC durability at very high power

- Low frequency (2MHz)
: Limited plasma striking capability at low pressure
More limited RIE mode plasma at low pressure

- Dual frequency (13.56MHz/2MHz)
: Best candidate for HAR process regime

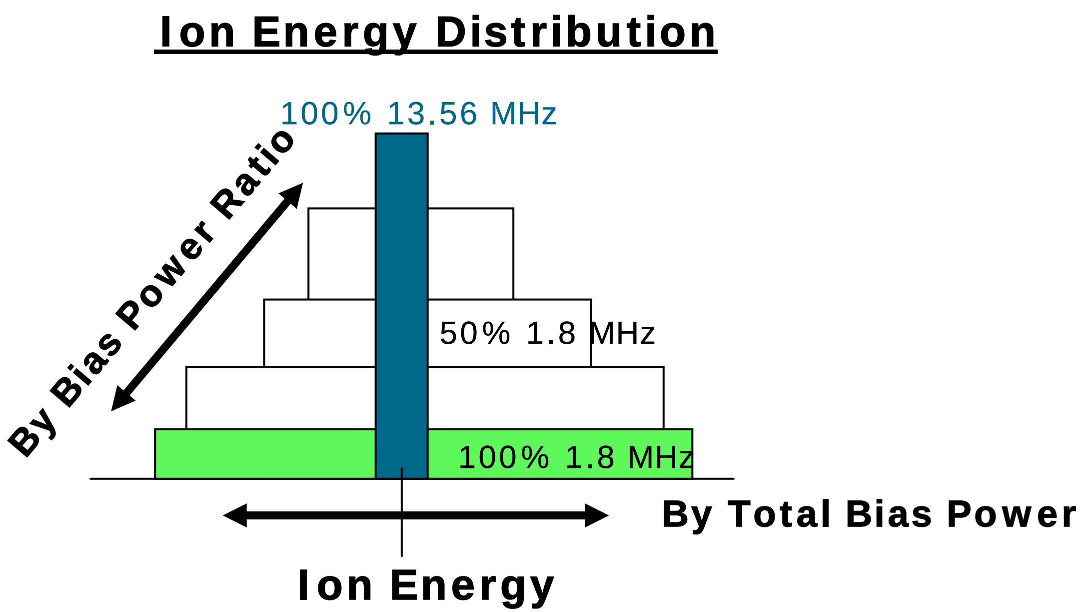
Enabler DFB Chamber Overview

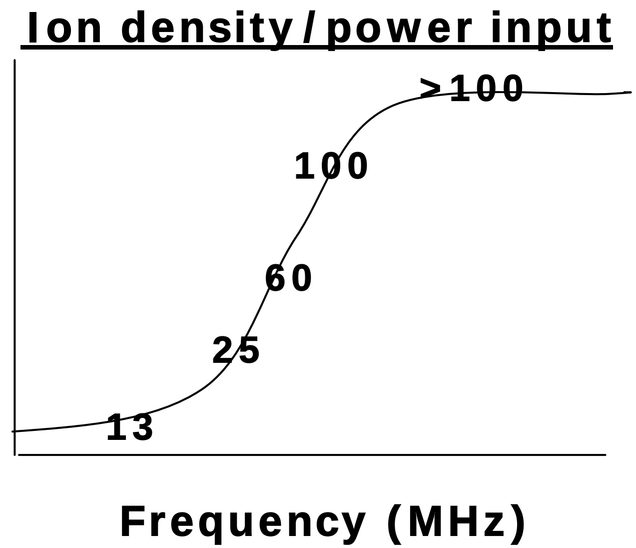


- Very high frequency source (>100MHz) giving very low DC bias on the top electrode
- Controllable plasma density and neutral dissociation for different applications
- Two additional knobs – CSTU and NSTU to tune etch rate and CD uniformities
- Very wide, easily tunable and usable operating windows
- Ion Energy Distribution tunability by DFB

Plasma Technology for Critical Etch

Dual Bias Frequency (1.8MHz + 13.56MHz) for Ion Energy Distribution (IEDF) Tunability



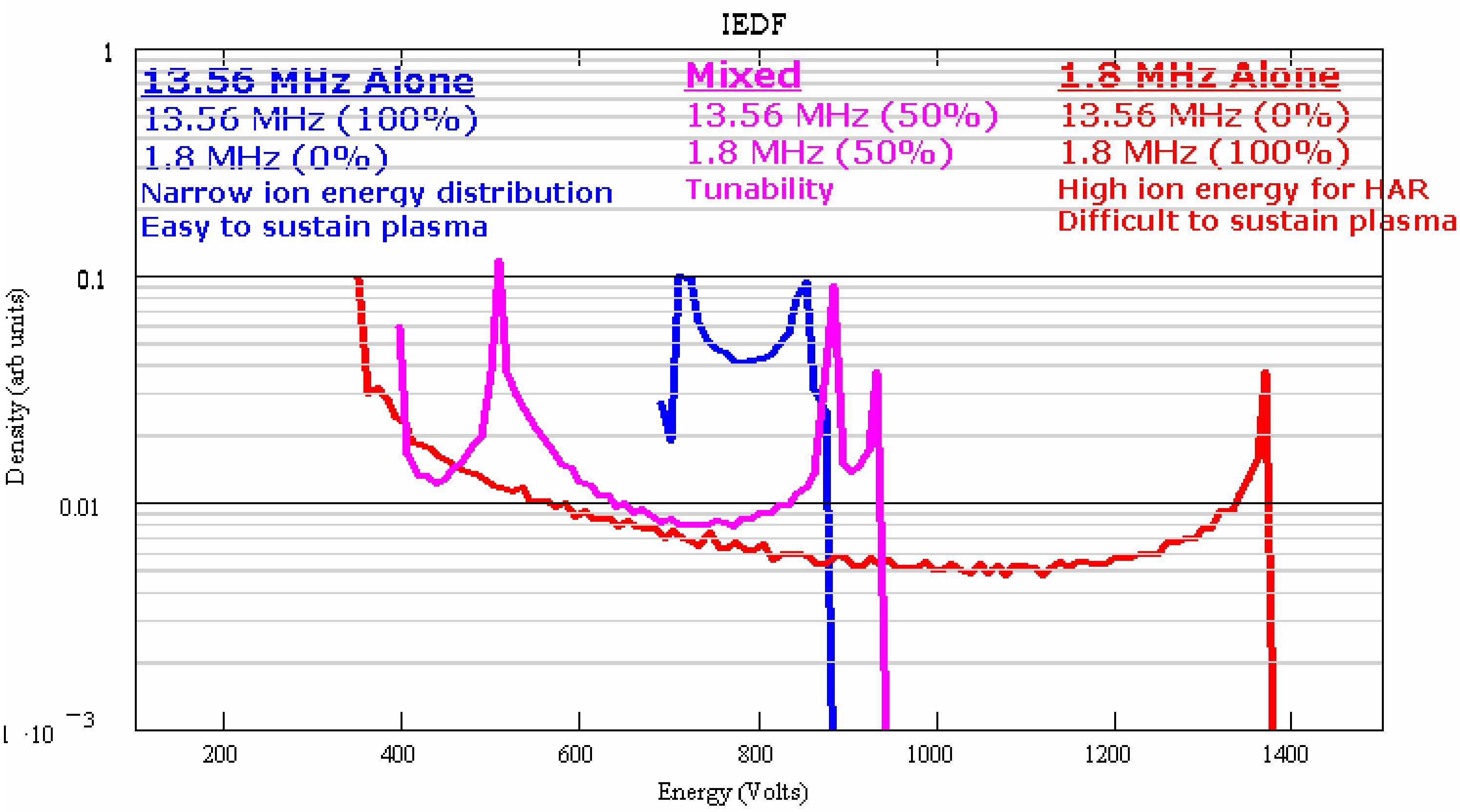


- The width of distribution is tunable by changing the bias power ratio of 2 frequencies
- The center of distribution is tunable by changing the total bias power

Application of 2 & 13 MHz bias enables ion energy tuning and maintains plasma density decoupling

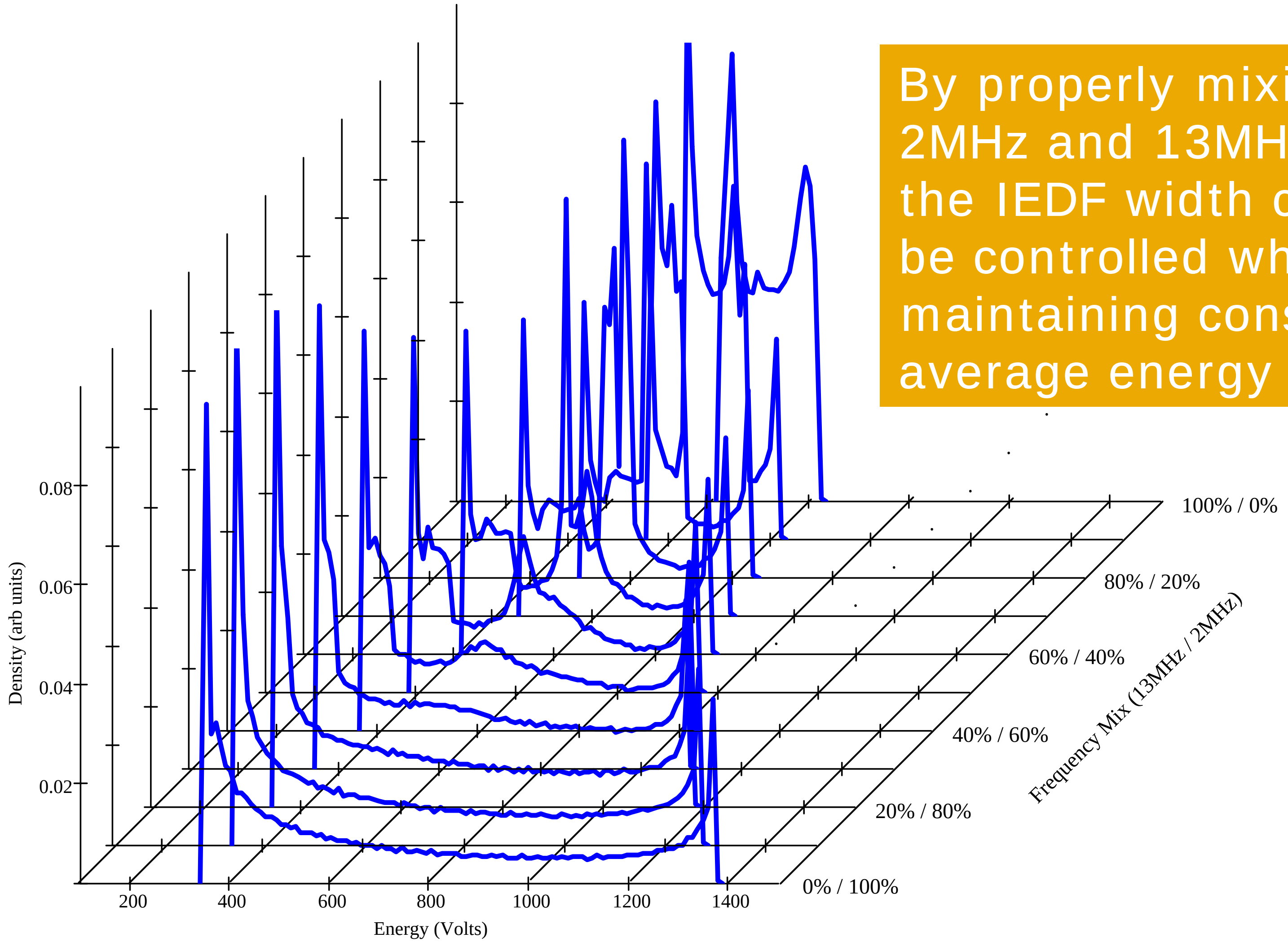
Dual bias frequency (2.0MHz + 13.56MHz) can provide the right ion energy distribution needed for future critical etch applications

Tunable Ion Energy Distribution by Dual Frequency Bias (2.0 / 13.56MHz)



IEDF Overlay–13MHz / 2MHz Mixing Fraction

Constant V_{pp} Waveform Across Sheath



By properly mixing 2MHz and 13MHz, the IEDF width can be controlled while maintaining constant average energy

Other Frequency Considerations

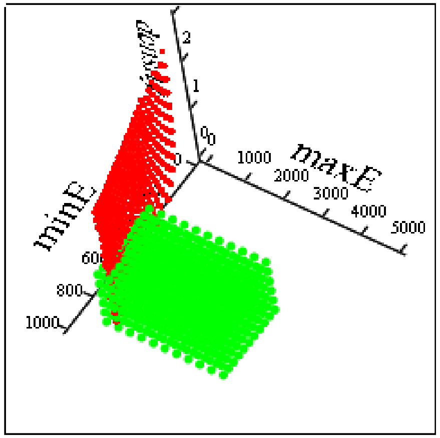
- 2 or 13MHz/VHF (and 2MHz/>100MHz)
  - Even though we top-launch, our >100MHz high voltage point is on the wafer (by design, typically V_{wafer}/V_{roof}~3)
  - The >100MHz rf voltages on the wafer are very low, so the major effect is source modifies 2 or 13MHz distribution by only relative density impact
- 2/27MHz or 2/60MHz
  - Complex: the 27MHz/60MHz contributes to both density creation and to ion energy adjustment
  - This leads to less orthogonality.
- 2/13MHz bias with >100MHz source
  - 2/13 achieves the "dialable" energy distribution
  - >100MHz independently adjusts the density effect

Window of Deep Etch Comparison

green is (n, E_{min}, E_{max}) space; **red** is achievable by Enabler

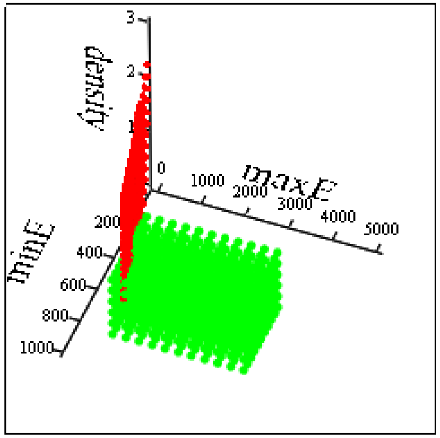
Single Frequency Bias with VHF source

10 mT



(vlow, vhigh, n), (eminopt, emaxopt, nopt)

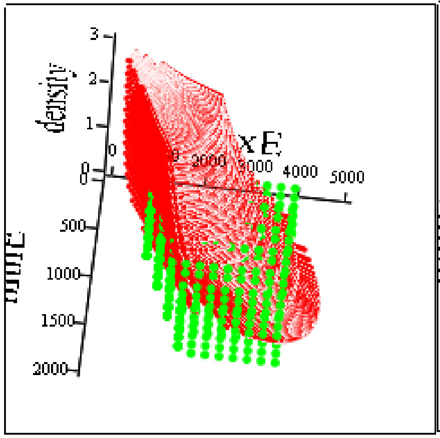
30 mT



(vlow, vhigh, n), (eminopt, emaxopt, nopt)

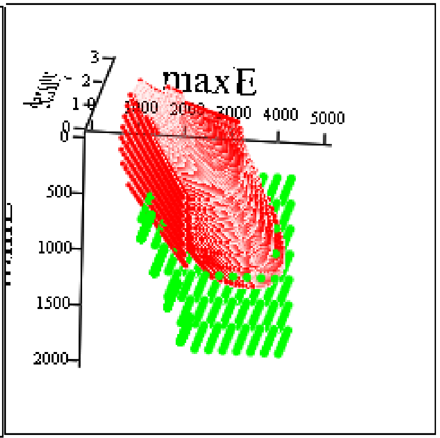
Dual Frequency Bias with VHF source

10 mT



(vlow, vhigh, n), (eminopt, emaxopt, nopt)

30 mT



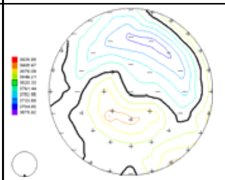
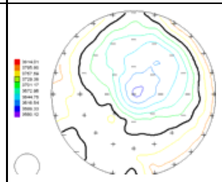
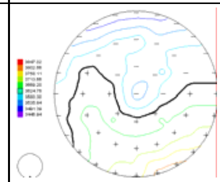
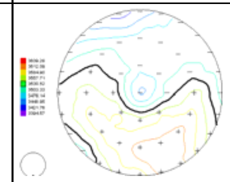
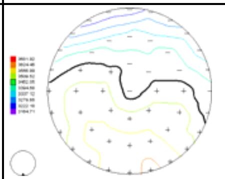
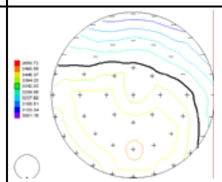
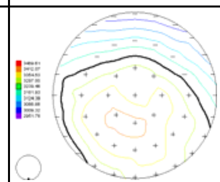
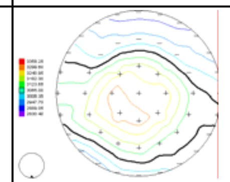
(vlow, vhigh, n), (eminopt, emaxopt, nopt)

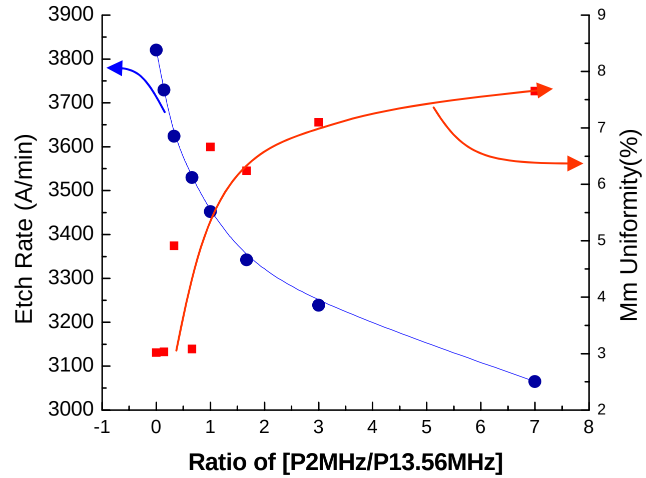
We can just achieve the lower end of this space, and only at lower pressures

Large fractions of the (n, E_{min}, E_{max}) volume are achieved

Blanket Thermal Oxide Etching with DFB

Baseline Process
(single frequency bias)

Bias Ratio (13.56MHz/2MHz)	13.56 only	7	3	1.7
Power Ratio (2MHz/13.56MHz)	0	0.14	0.33	0.6
Cotour Map				
Etch Rate(A/min)	3820	3729	3624	3530
Uniformity(1sigma,%	1.5	1.52	2.3	1.59
Uniformity(M-m,%)	3.02	3.03	4.91	3.08
Bias Power(W) (13.56MHz-2MHz)	1	0.6	0.33	0.14
Power Ratio (2MHz/13.56MHz)	1	1.67	3	7
Contour Map				
Etch Rate(A/min)	3452	3342	3239	3065
Uniformity(1sigma,%	3.41	3.55	3.99	4.25
Uniformity(M-m,%)	6.66	6.24	7.1	7.65

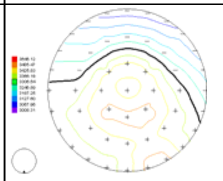
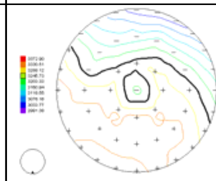
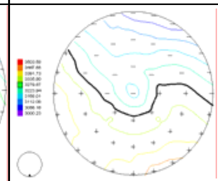
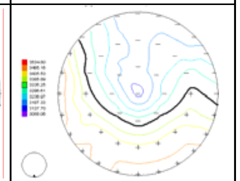
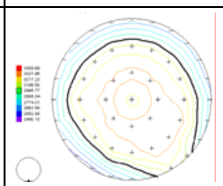
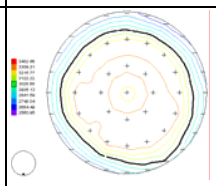
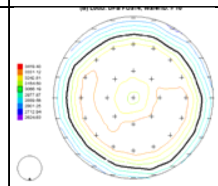
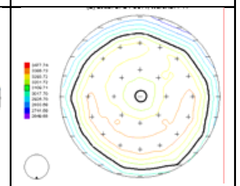


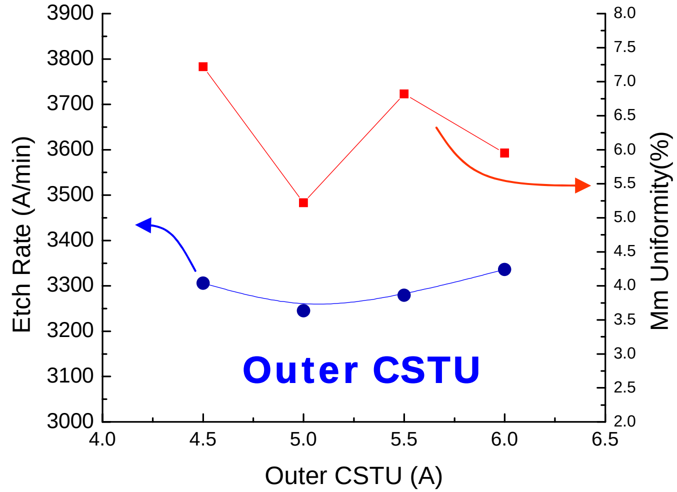
As 2MHz fraction increases, uniformity is getting worse but tends to be saturated at 7% Mm over 1:1 ratio and also etch rate drops due to lower density.

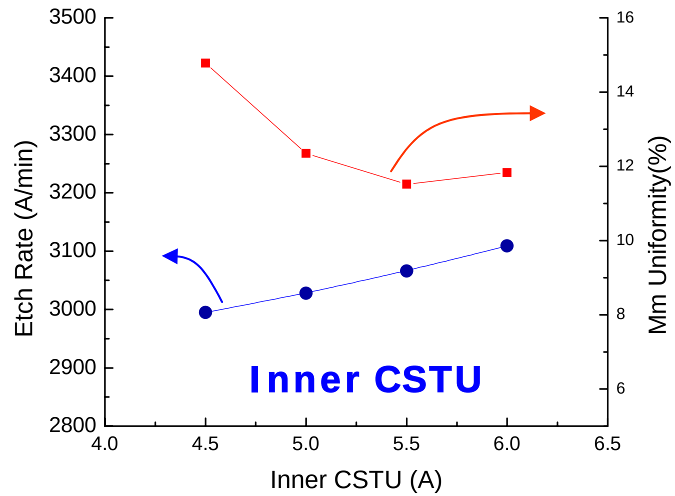
Uniformity Tuning by CSTU

Baseline Process

Dual Frequency Bias (75% 2 MHz) vs CSTU

Outer CSTU(A)	4.5	5	5.5	6
Cotour Map				
Etch Rate(A/min)	3306	3245	3279	3336
Uniformity(1sigma,%	4.26	3.21	3.7	3.81
Uniformity(M-m,%)	7.22	5.22	6.82	5.95
Inner CSTU(A)	**4.5**	**5**	**5.5**	**6**
Contour Map				
Etch Rate(A/min)	2996	3028	3066	3109
Uniformity(1sigma,%	10.7	9.72	8.75	8.27
Uniformity(M-m,%)	14.78	12.35	11.52	11.83

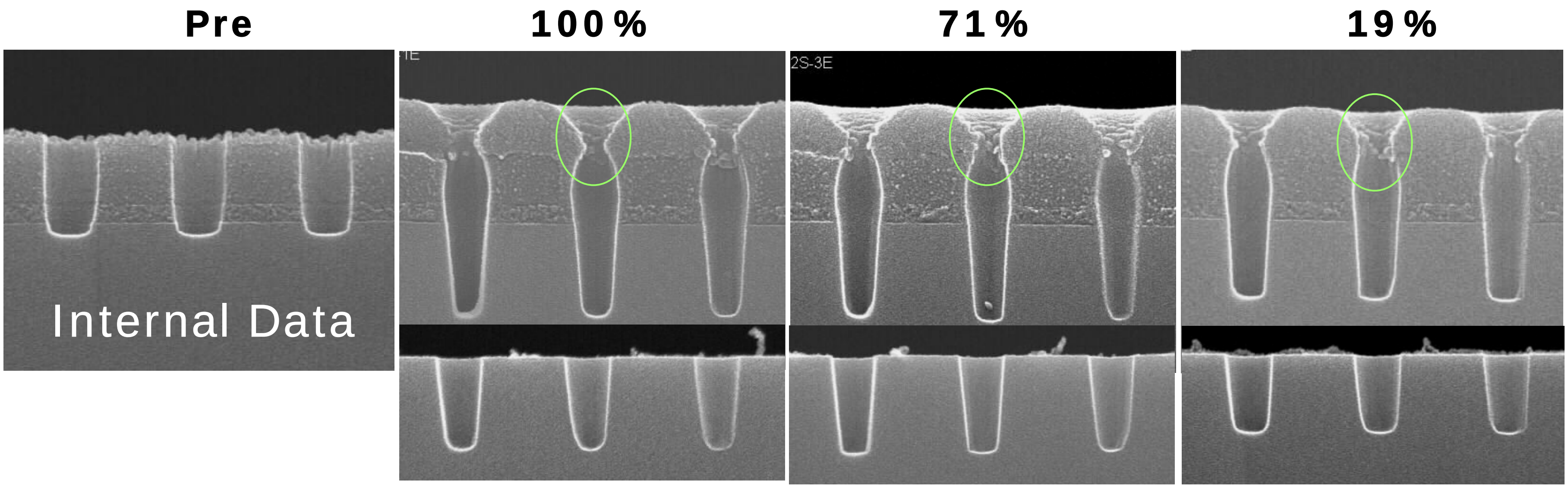




Outer CSTU looks more effective to tune the etch rate uniformity

Polymer Deposition Shape With DFB

$P_{13.56MHz} / (P_{13.56MHz} + P_{2MHz})$

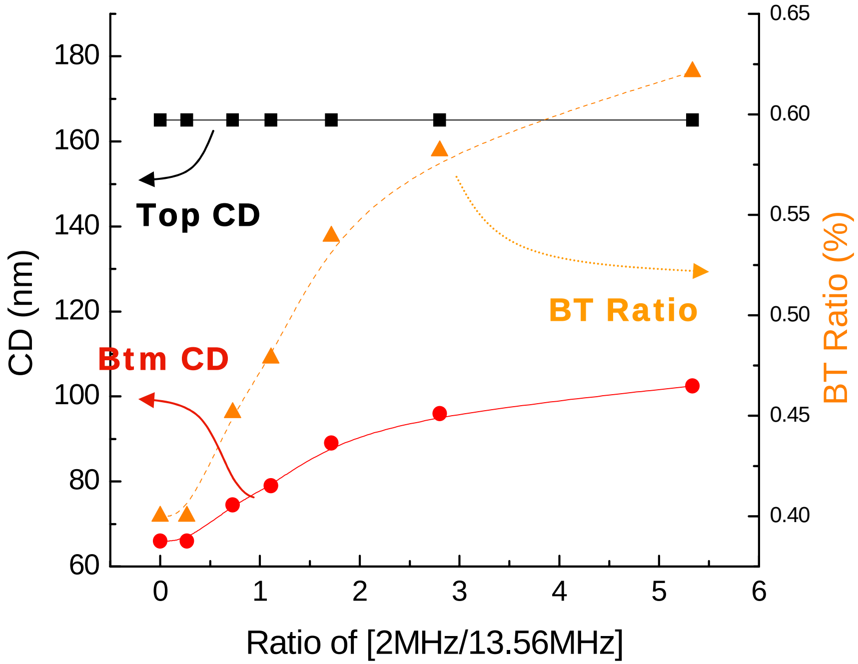


- Higher ratio of [2MHz/13.56MHz]
  - Less sidewall polymer deposition,
  - Reduce necking and bowing.
  - Etch front improved with the mixed bias powers

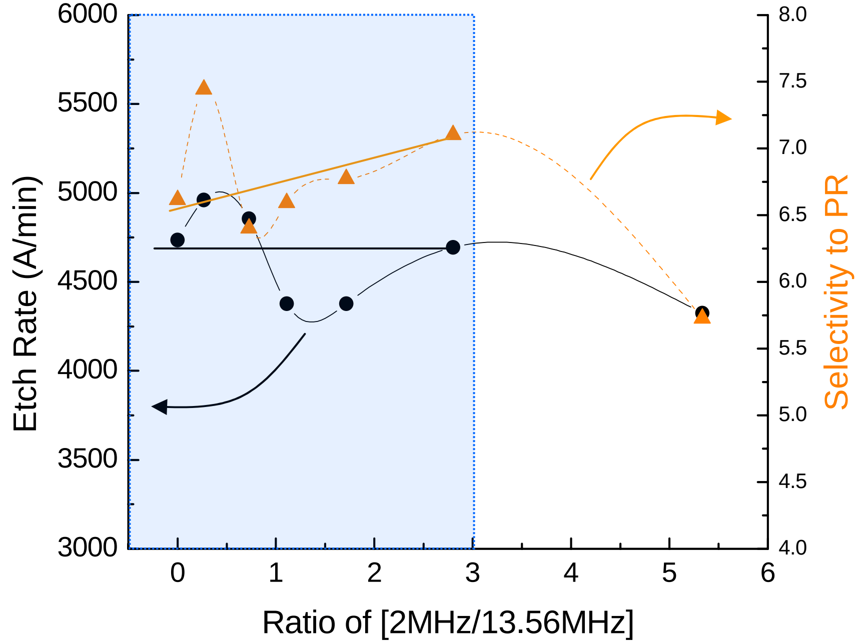
Pattern Wafer Etching with DFB

0.18µm hole / 248nm resist / TEOS

Top / Btm CD & BT Ratio vs. DFB Ratio



Etch rate & Selectivity to PR vs. DFB Ratio



As 2MHz fraction increase (up to 1:3)
- **Profile is getting more vertical (Btm CD / BT ratio increase)**
- **No significant effect on etch rate**
- **Selectivity to resist increases**

ENABLER

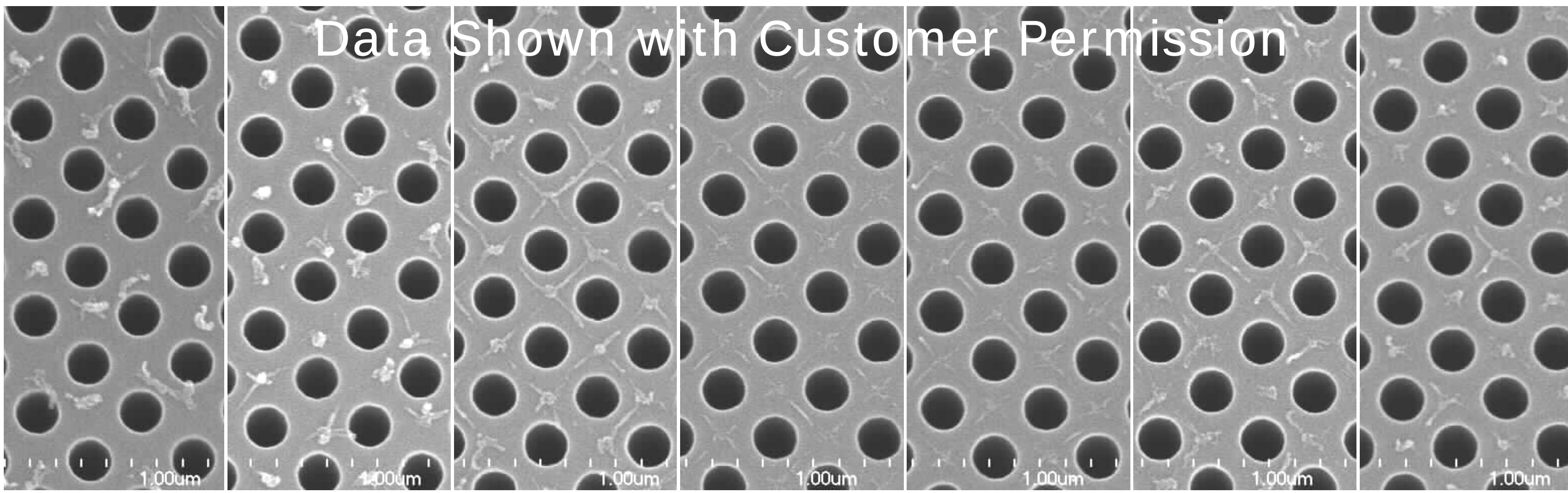
WS Lee
APPLIED MATERIALS®

Striation Comparison with DFB

0.18μm hole / 248nm resist / TEOS

$$P_{13.56MHz} / (P_{13.56MHz} + P_{2MHz})$$

100% 78% 57% 47% 37% 26% 16%

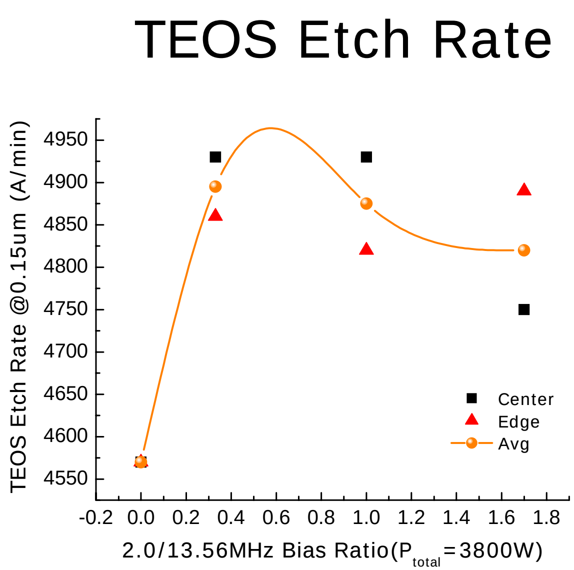


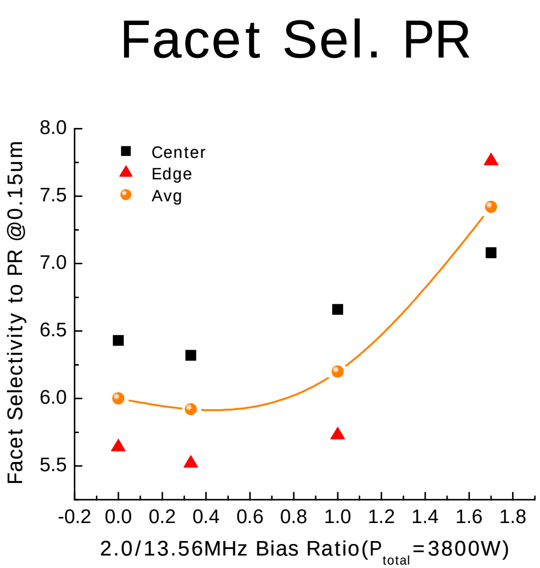
More 2MHz Fraction

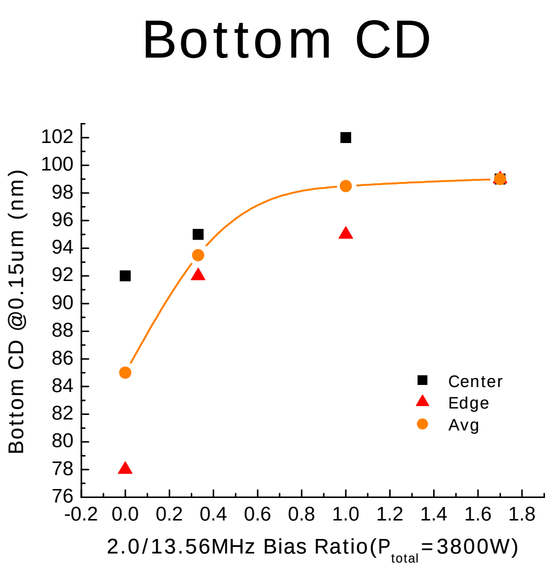
No impact on striation (resist integrity)

Pattern Wafer Etching with DFB

0.15µm hole / 248nm resist / TEOS



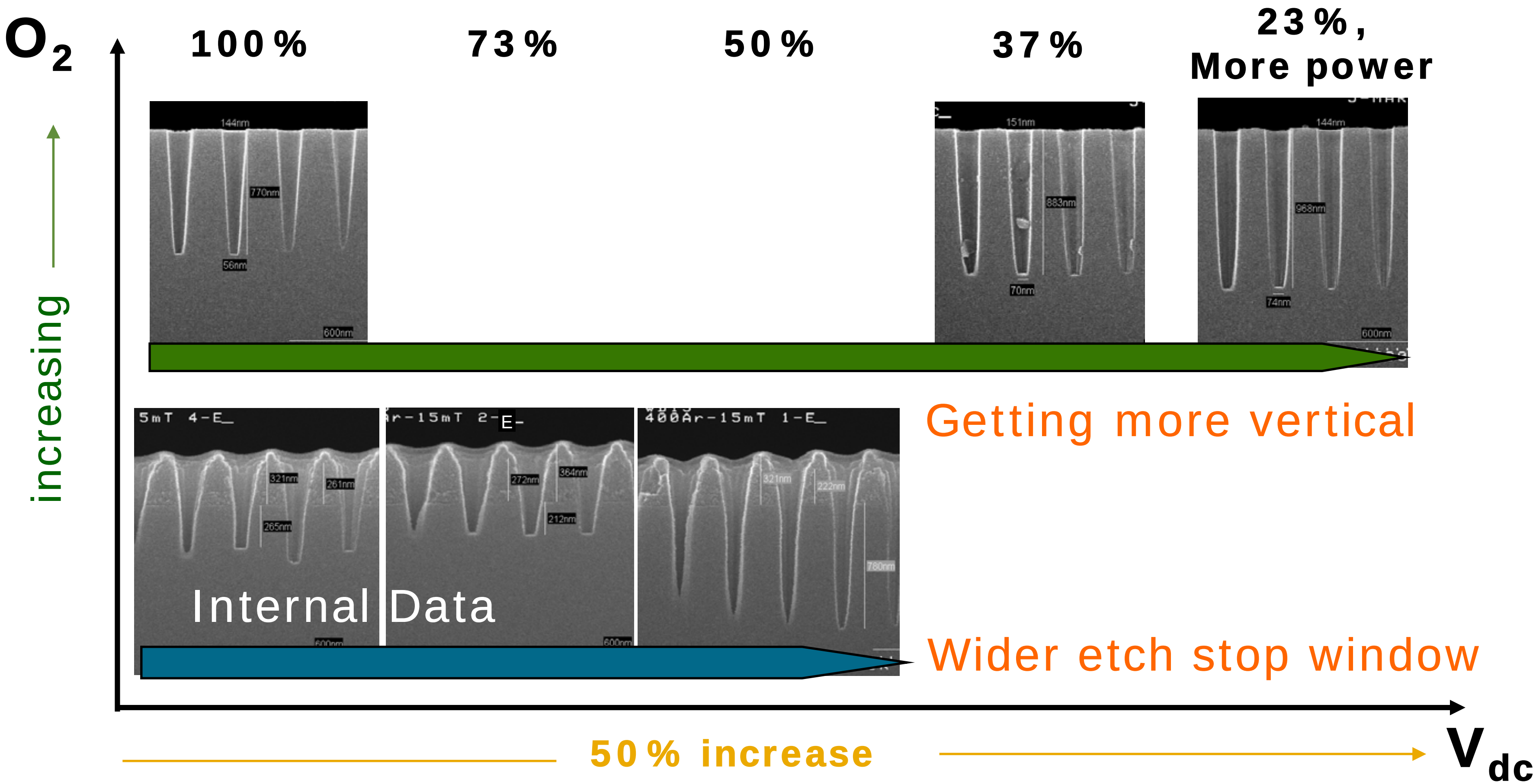




Almost same trend as 0.18um etching characteristics

Etch Stop Window and Etching Profile vs DFB Mix (x% 13 MHz power)

$$P_{13.56MHz} / (P_{13.56MHz} + P_{2MHz})$$

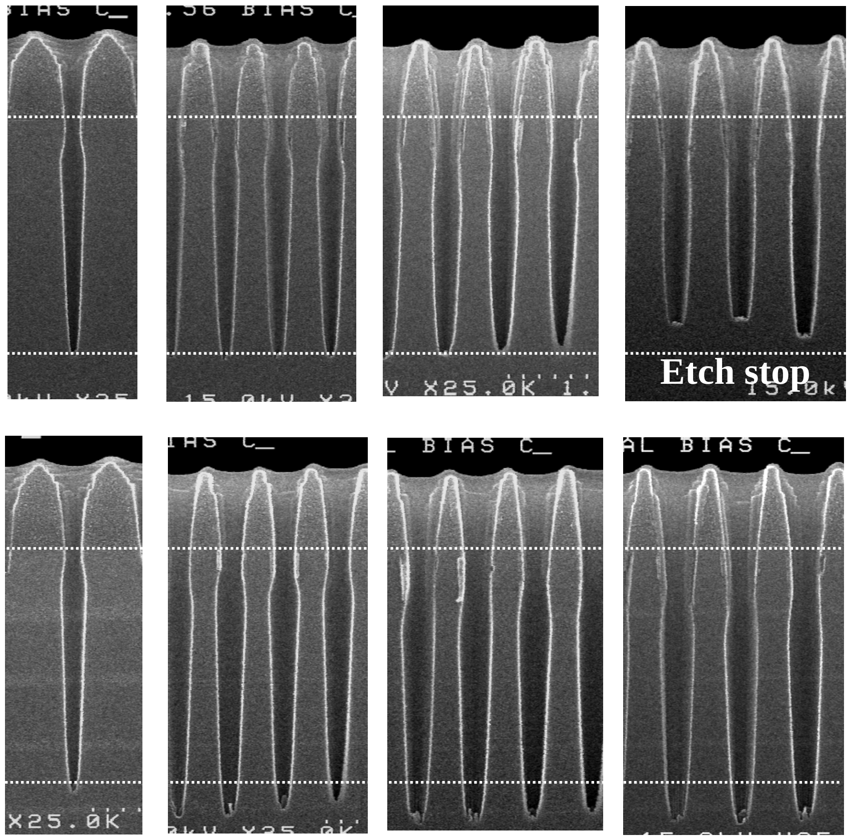


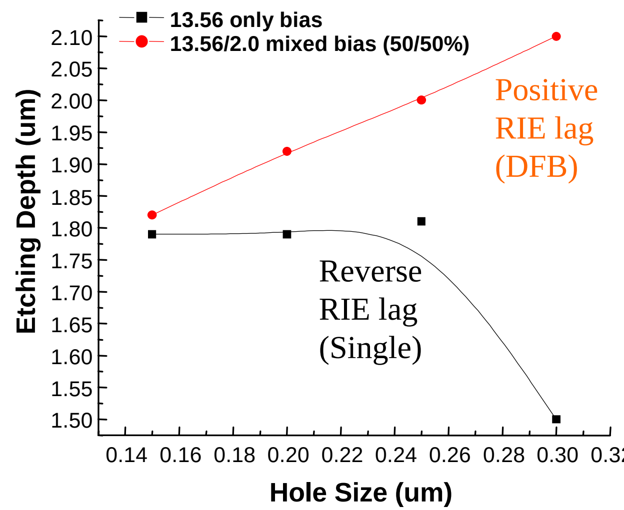
RIE Lag (ARDE) vs DFB Ratio

Hole size 0.15um 0.20um 0.25um 0.30um

13.56MHz only

Mixed DFB 50%

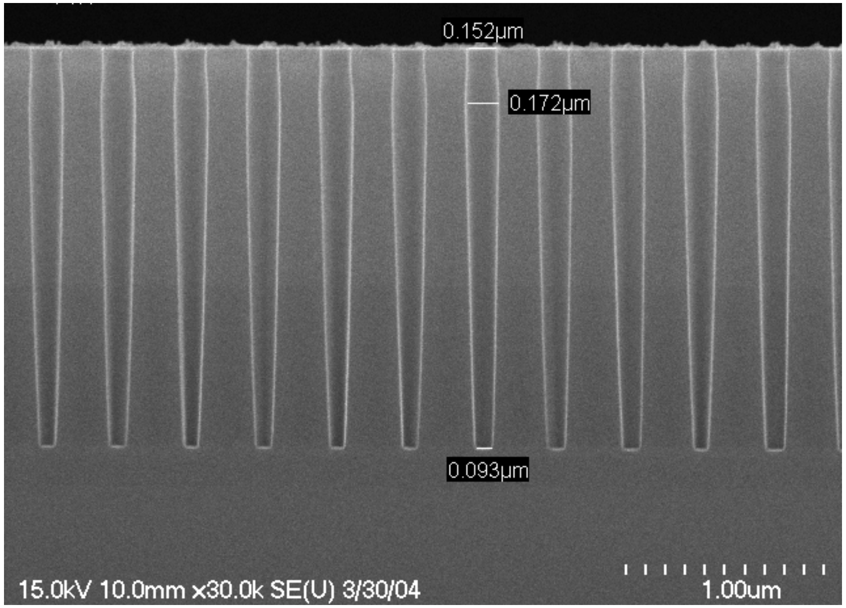




Internal Data

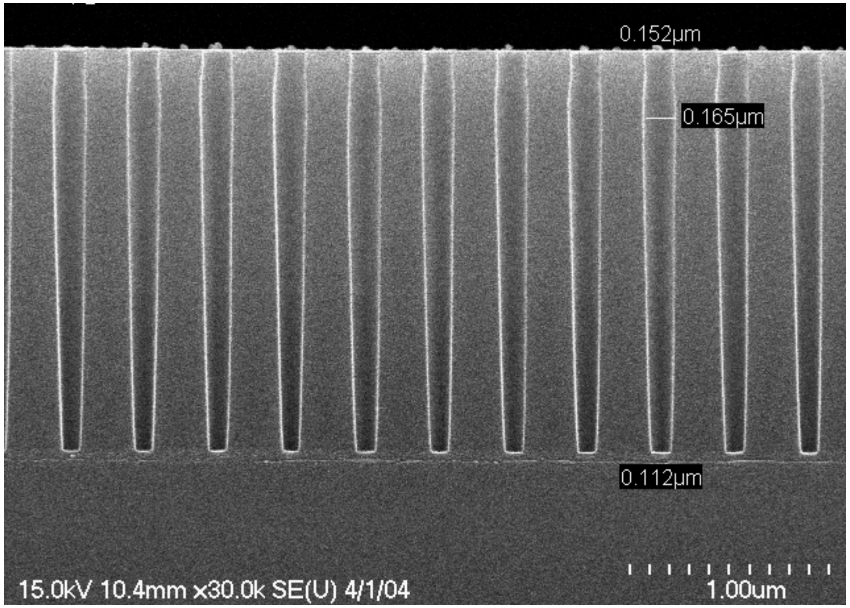
Optimized Process Comparison Between 13.56MHz Single and 13.56/2MHz Dual frequency Bias

13.56MHz only



Top CD 152nm
Btm CD 93nm
Bow CD 172nm

13.56MHz/2.0MHz Mixed



Top CD 152nm
Btm CD 112nm
Bow CD 165nm

Conclusion

- Dual bias 2/13.56 MHz frequency with VHF source is capable of modulating ion energy distribution while maintaining similar ion density
- Combination of VHF source(>100MHz) and 2/13.56 MHz dual frequency bias has wider process window
  - Larger bottom/top CD ratio
  - Wider etch stop window
  - Better control of microloading/RIE lag
  - Some selectivity improvement
  - No striation dependence on the bias power ratio