EFFECT OF SECONDARY ELECTRON EMISSION ON SURFACE CHARGING DURING PLASMA ETCHING FOR MICROELECTRONICS FABRICATION

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Motivation

- During plasma etching, charging within the feature generates intra-feature electric fields that distort ion trajectories, leading to defects in the feature.
- Secondary electrons (SEs) are emitted when charged particles, high energy neutrals and photons strike the surface, leading to extra charging of the feature.
- In this work, a computational study was conducted to investigate the effect of secondary electron emission (SEE) on charging within a predefined high aspect ratio (HAR) feature.
- Parametric studies on **voltage amplitude** and **aspect ratio** were conducted.

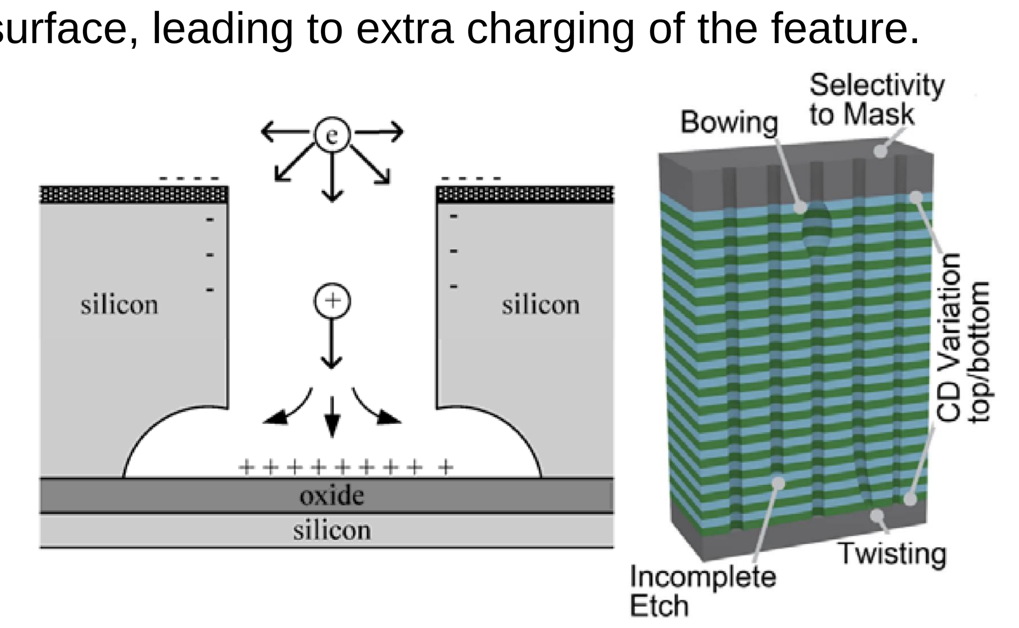

Fig 1. *Charging in the feature (left)[1] and types of defects (right, Source: Lam Research).*

Methodology

Hybrid Plasma Equipment Model (HPEM)[2]:

- Heavy particles (ions/neutrals) are addressed by **multi-fluid approach**.
- **Continuity**, **momentum** and **energy** equations are solved.
- Electrons are addressed by **electron Monte Carlo Simulation** (eMCS) module to produce their distribution functions.
- **Plasma Chemistry Monte Carlo Simulation** (PCMCS) is used to produce **the ion and electron energy and angular distributions** onto the wafer.

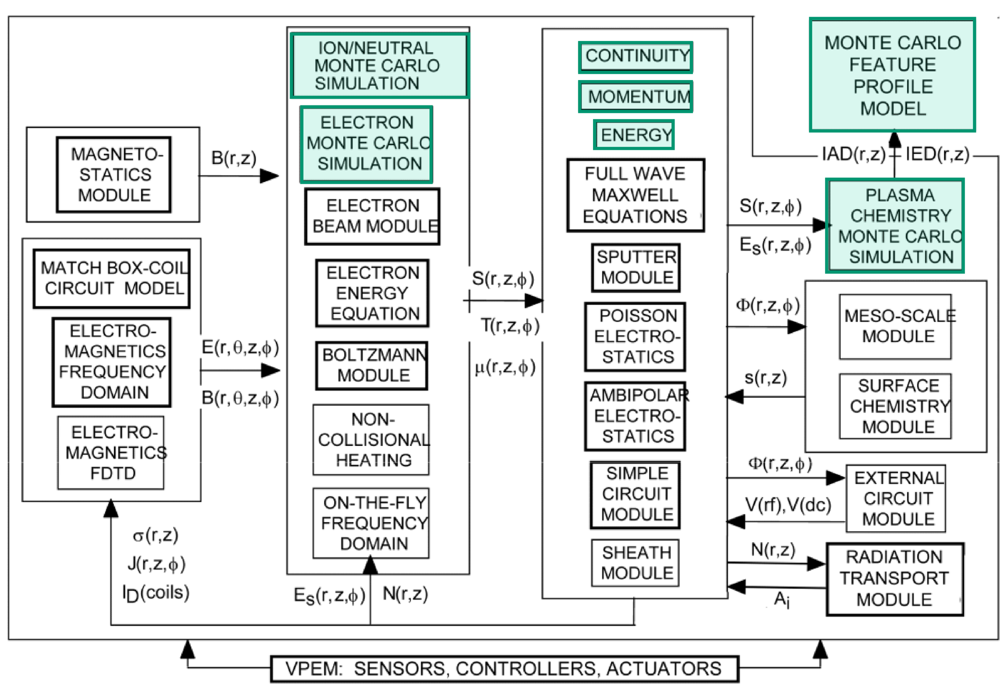

Fig 2. *Schematics of Hybrid Plasma Equipment Model*

Monte Carlo Feature Profile Model (MCFPM):

- Multidimensional feature scale model that simulates the etching and charging properties of the profile.
- Pseudoparticles are launched at the top of the feature and are tracked until they react with the solid.
- **Ion and electron energy angular distributions** from HPEM are input into MCFPM for energy and angle of pseudoparticles.
- Electric potential: $-\nabla \cdot \varepsilon \nabla \Phi = \rho$

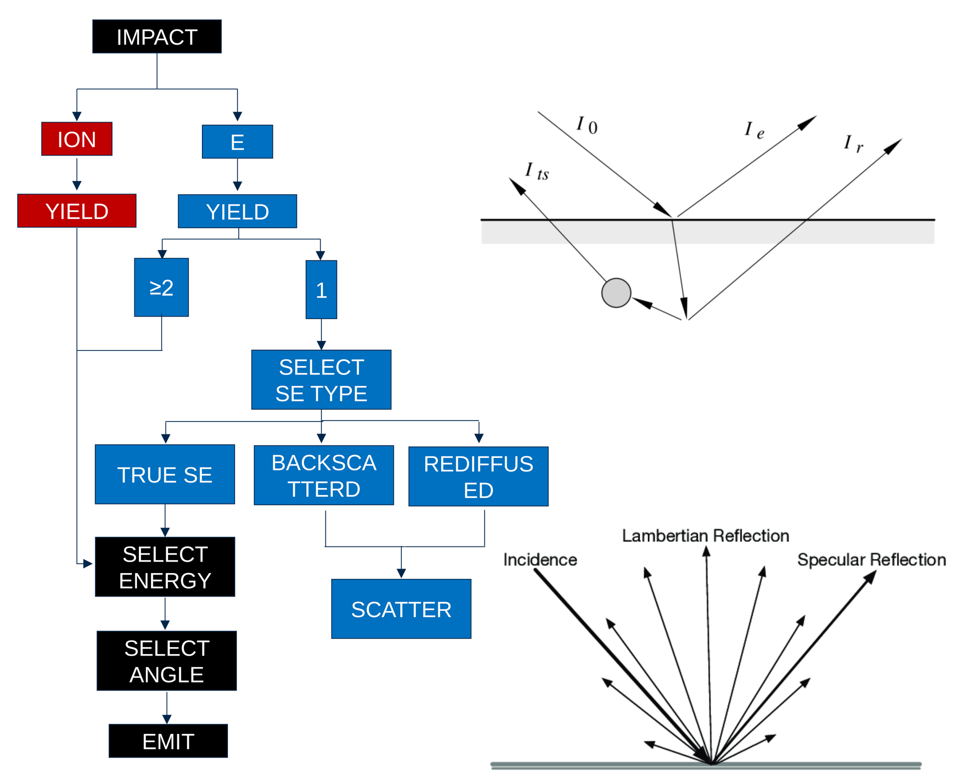

Fig 3. *Schematics of Secondary Electron Emission Routine*[3]

Reactor Simulation Result

HPEM Geometry:

- Continuous wave single frequency capacitively coupled plasma (CCP) RF etching reactor.
- Ar, 500 sccm flowrate
- 10 mTorr
- 150-450 V at 20 MHz

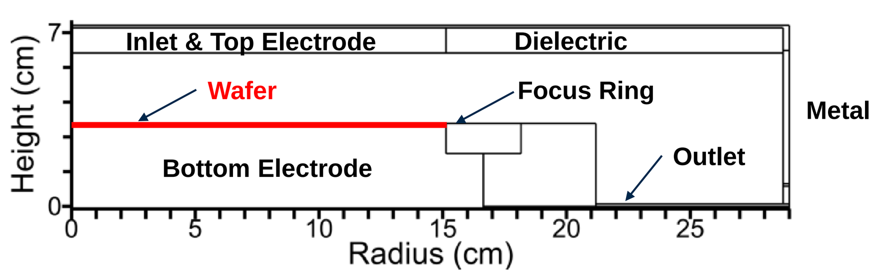

Fig 4. *Illustration of reactor geometry.*

Results:

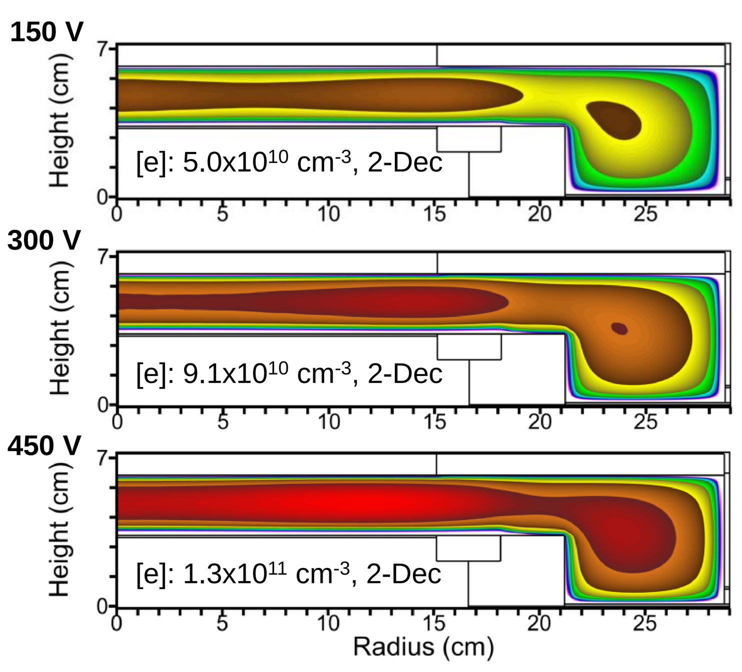

Fig 5. *Electron densities in the chamber.*

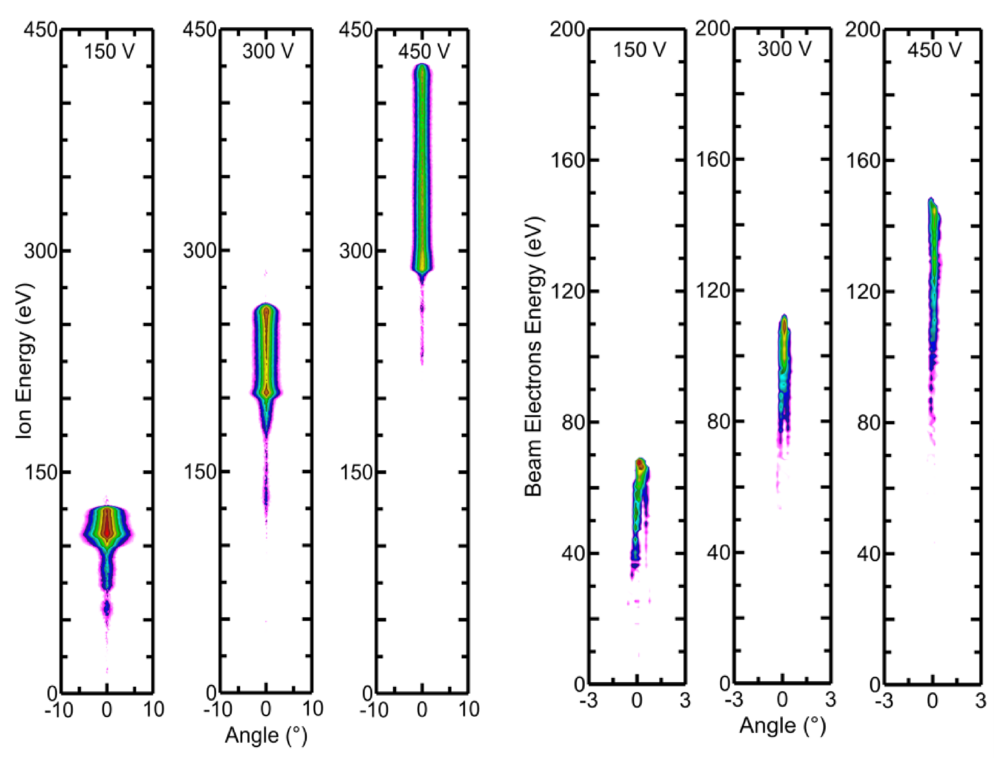

Fig 6. *Ion energy angular distribution (left) and beam-like electron energy angular distribution (right)*

Charging in a HAR Feature

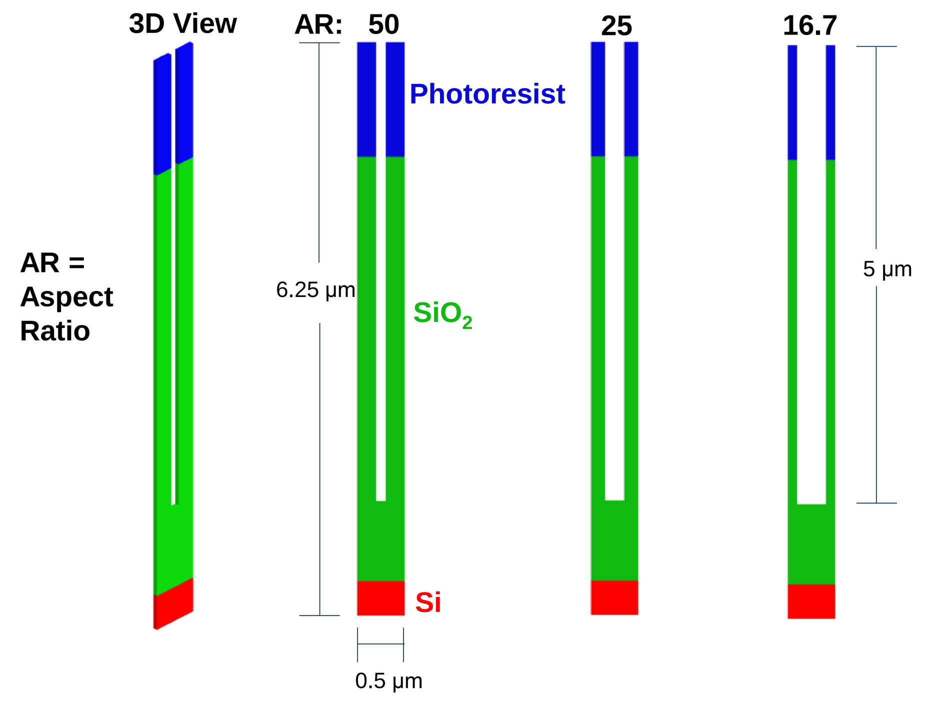

Fig 7. *Feature dimensions.*

Feature dimension:

- Aspect ratio: 50
- SiO2 wafer
- Total height: 6.25 μm
- Total width: 0.5 μm
- Critical dimension: 0.1 μm
- Trench depth: 5 μm

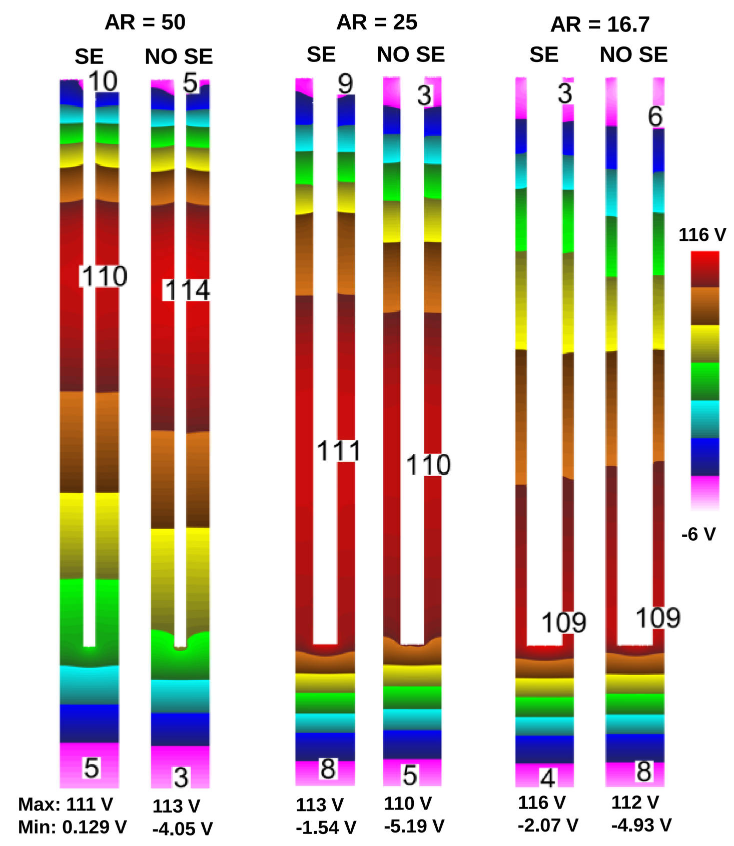

Fig 8. *Electric potential at 150 V.*

- SEs are capable of **redistributing charges** and depositing at a different location.
- AR = 50: Charge redistribution **lowers** the electric potential.
- AR = 25 and 16.7: charged species strike the bottom, emitting SEs vertically in situ.
- At large width, SEE at the sidewalls **broadens** the potential distribution.

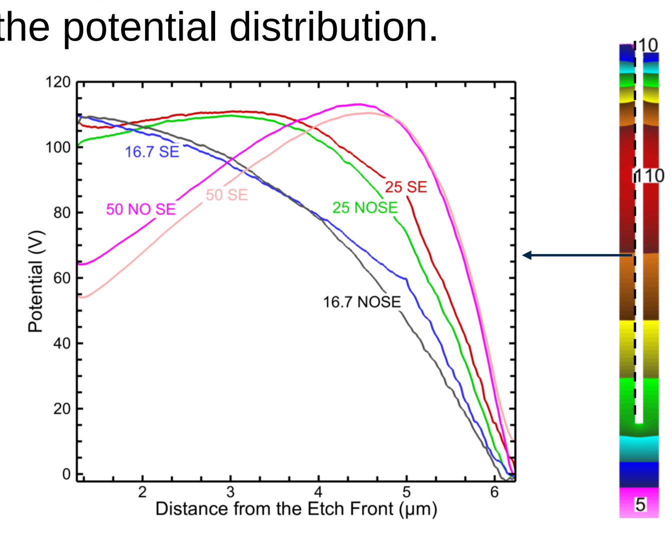

Fig 9. *Electric potential along the sidewall*

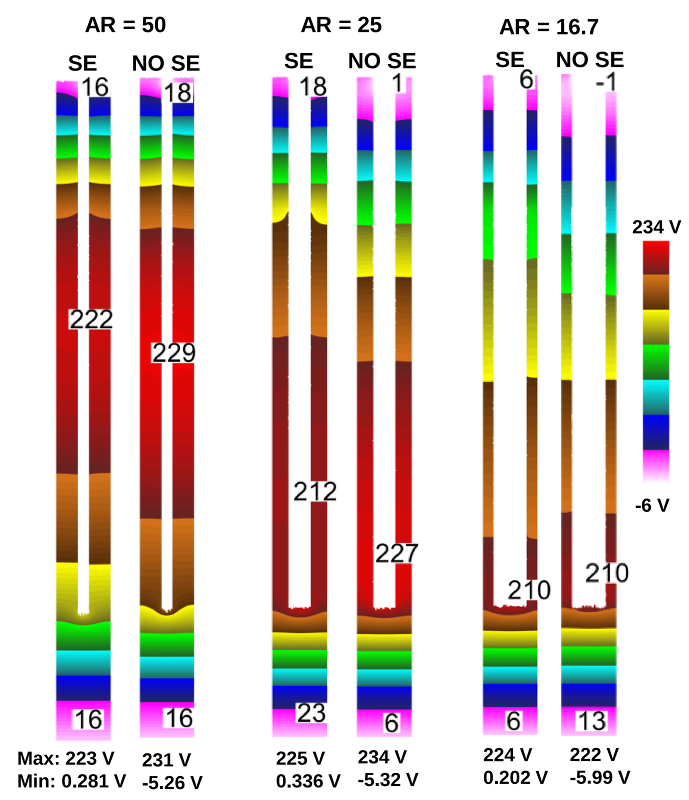

Fig 10. *Electric potential at 300 V.*

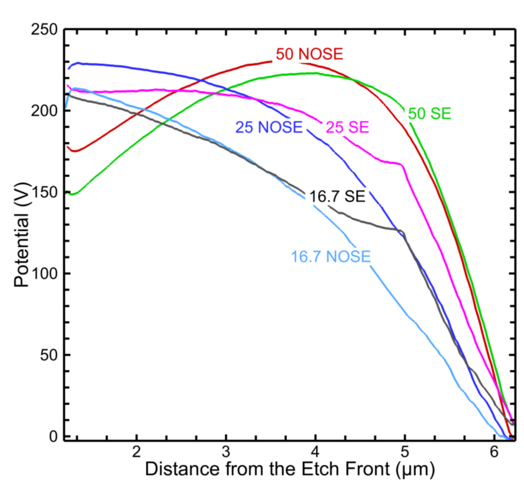

Fig 11. *Electric potential along the sidewall.*

- AR = 50 to AR = 25: Ions reach the bottom, whereas the electrons collide with upper sidewalls.
- AR = 25 to AR = 16.7: Increased width facilitates electron impact on the bottom.
- Charge is neutralized at the bottom from SEs emitted at sidewalls .
- AR = 25: High electric potential in the center due to SEE and lower potential at the bottom due to **neutralization**.

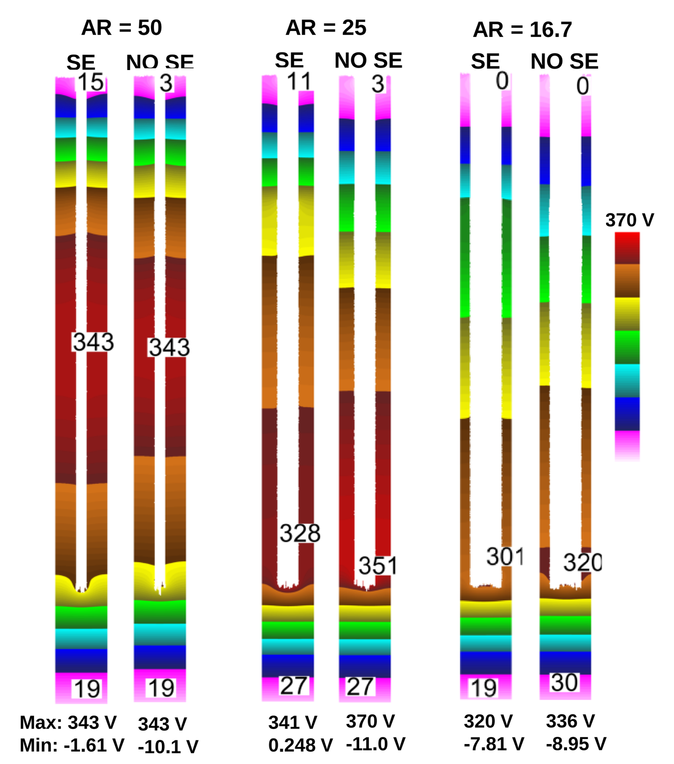

Fig 12. *Electric potential at 450 V.*

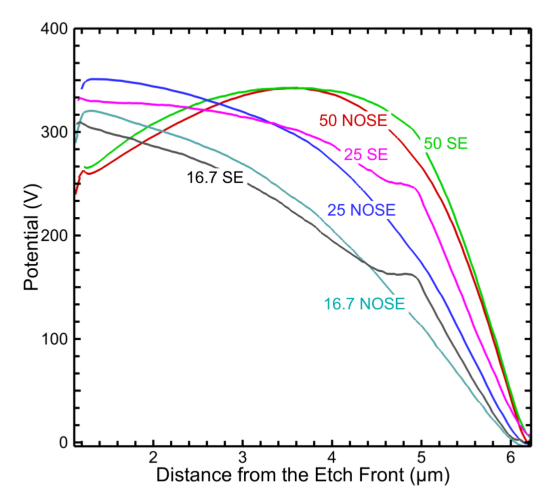

Fig 13. *Electric potential along the sidewall.*

- AR = 50: The majority of SEs deposit their charges in adjacent regions.
- AR = 25 and 16.7: potential buildup at the bottom confines SEs.
- Simultaneously, SEs emitted from the top are accelerated downward.
- While SEs emitted at the bottom remain at the bottom, SEs from the top **neutralize** positive charge at the bottom.

Conclusion

- At low voltages, potential buildup is not sufficient enough to trap the SEs emitted from the bottom of the feature.
- As the AR decreases (wider) electric potential becomes slightly more positive as SEs escape from the bottom of the feature.
- At high voltages, the trends reverse. Significant potential buildup and traps SEs emitted from the bottom while SEs emitted at the sidewalls neutralize positive charge at the bottom.

References

[1] Y. Wang, et al., Proc. 7th IEEE NANO, Hong Kong, 2007.
[2] M. J. Kushner, J. Phys: D., 2009.
[3] M. A. Furman, et al., Phys. Rev. ST Accel. Beams, 2002.

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