# Optimization of Deep Hole Etching in Silicon for 3-D X-ray Detectors

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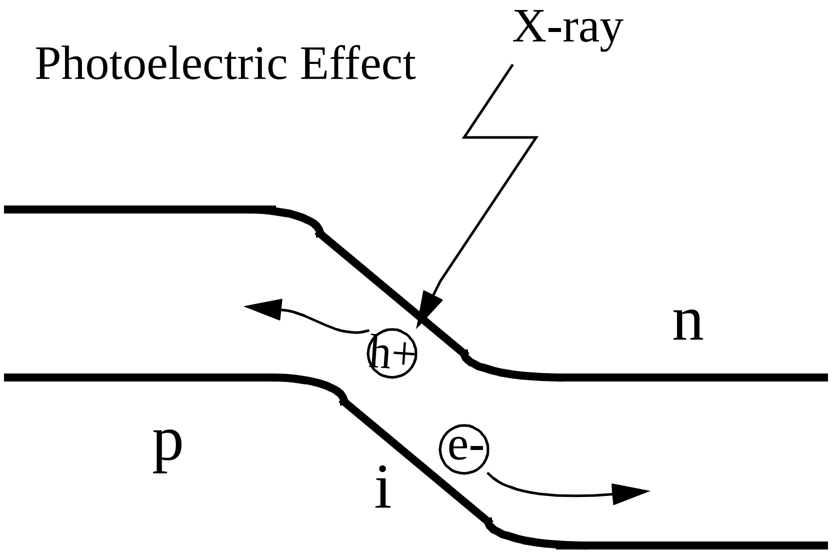
# X-ray Detector Arrays

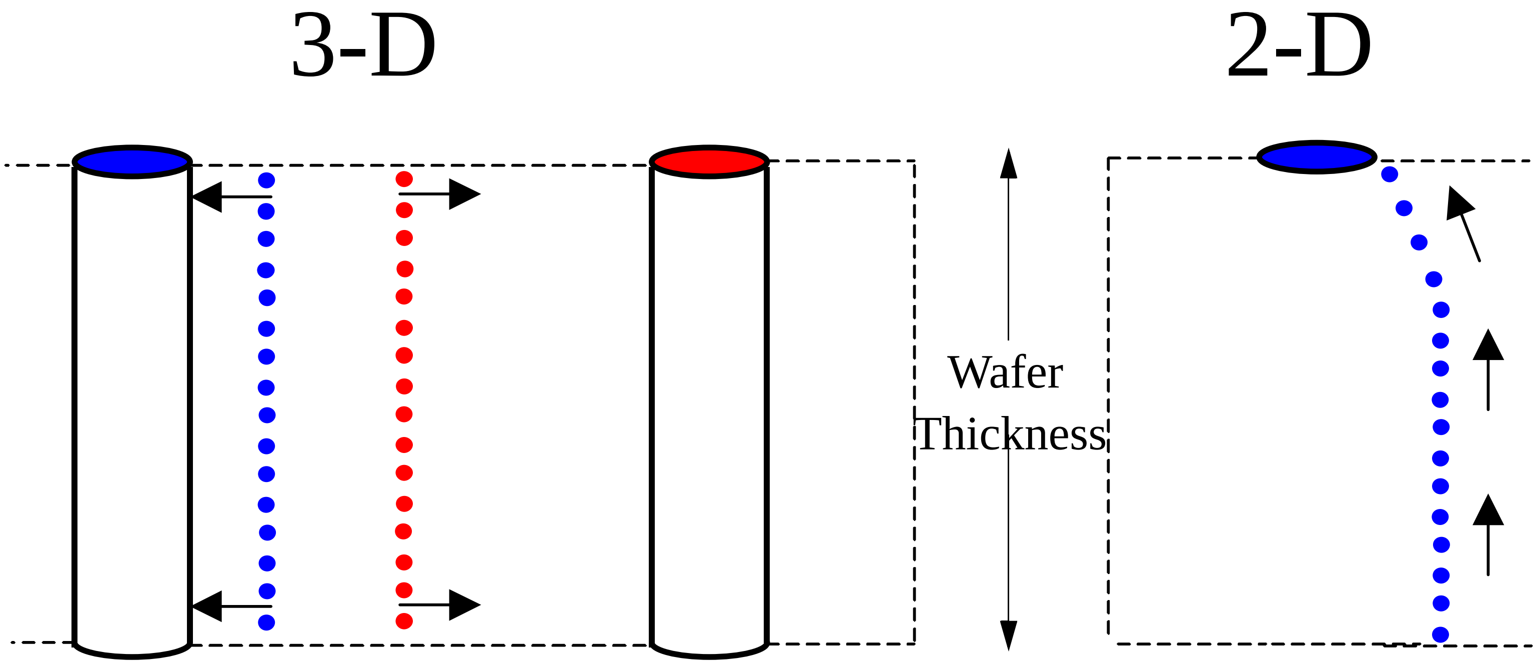
- “Digital Camera” or “CCD” type of device for X-rays
  - Resolution
  - Dynamic range/Sensitivity
  - Spectral response/linearity
  - Speed or Frame Rate (“real time processing for High-Energy Physics”)
  - Radiation hard

Desirable design criteria:

- Ultrapure material
- Large Si collection volume
- Small pixel spacing
- Small electrode-electrode spacing

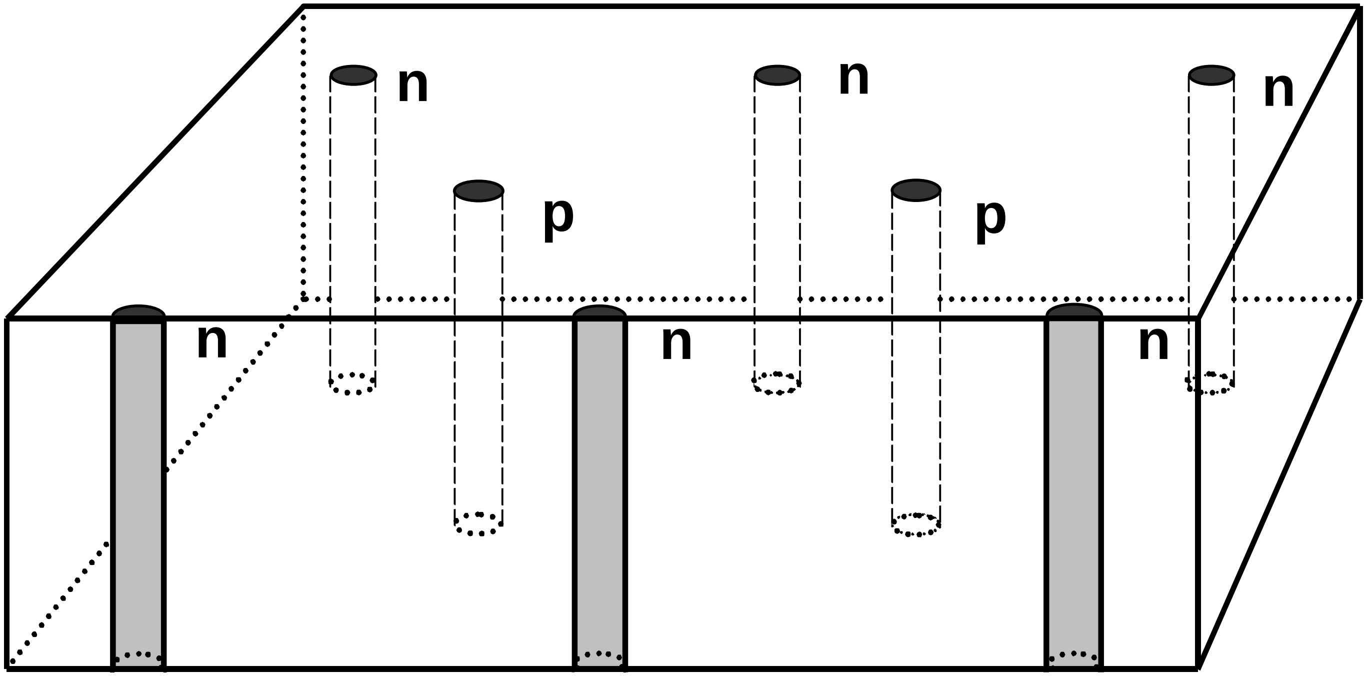


# Competing technology:  Planar devices



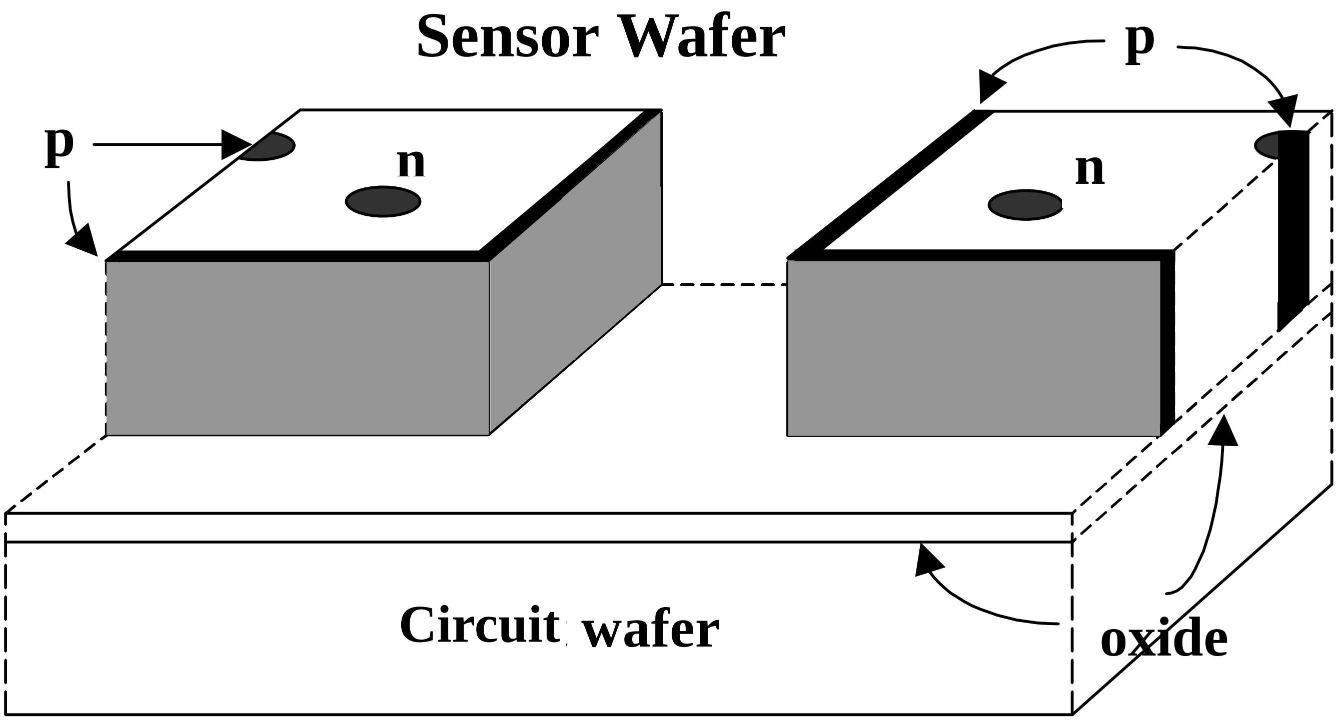
- 3-D: wafer thickness / electrode spacing independent ⇒ shorter distances ⇒ Faster!
- 3-D “cylinders” provides higher average field for any given maximum field
- 3-D allows incident track location to be pinpointed.
- 2-D simpler- no messy processing.
- 2-D has lower $C_{electrode}$

# Objective: Very deep holes (through wafer?) with minimal volume



- Holes through the wafer form vertical electrodes.
- Electrodes part-way through is possible, but concerns of E-field at tip of hole.

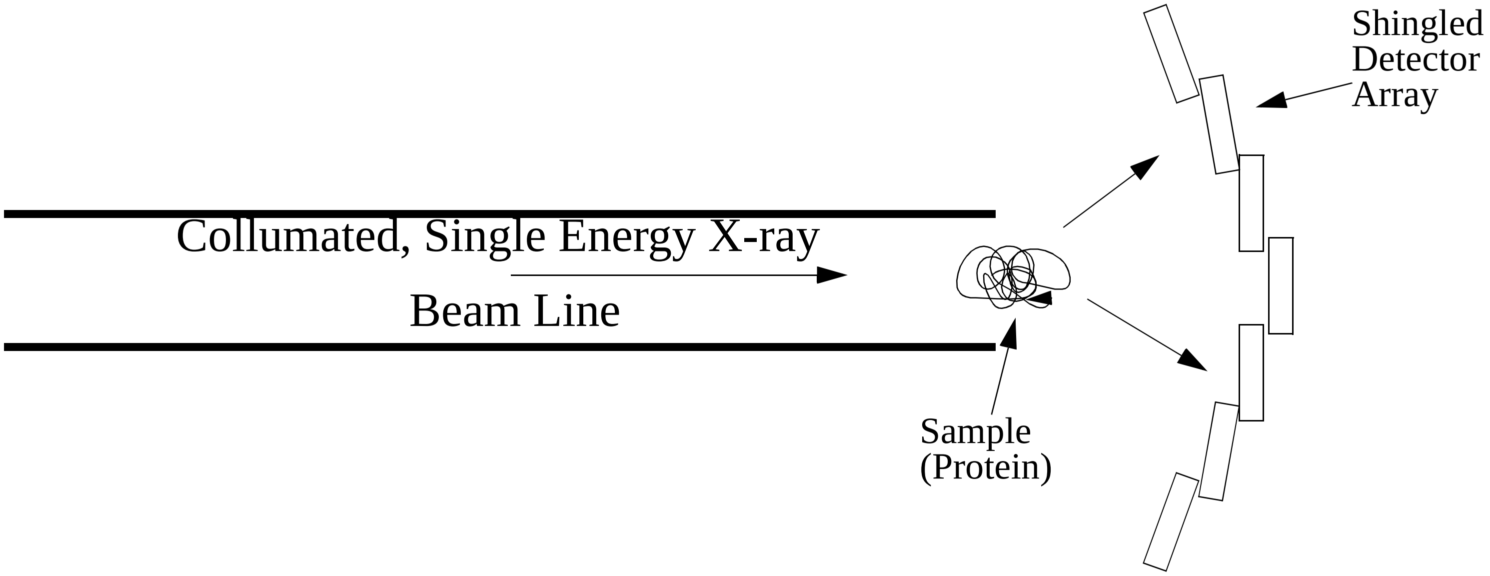
# Detector Construction



- Complete detector requires sensor wafer to be bonded to circuit wafer.
- Circuit fab done by foundry.  Sensor wafer requires support wafer in process.

# Applications

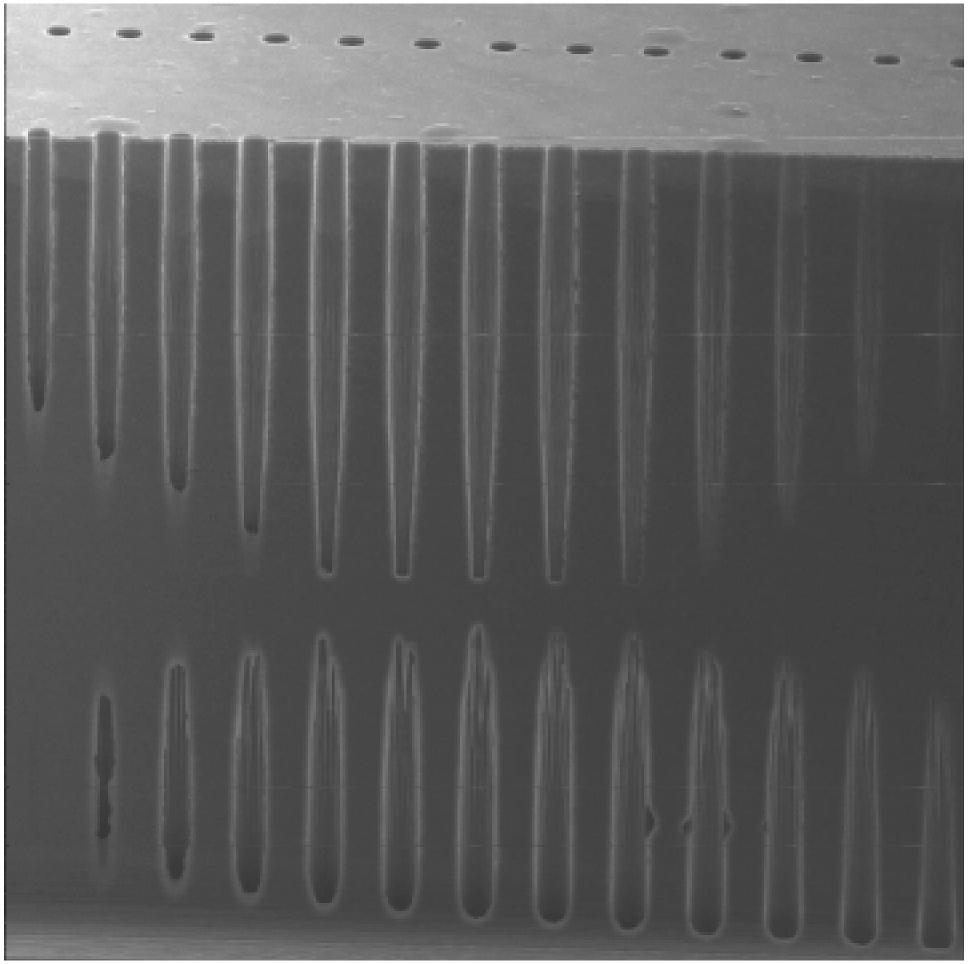
- High-Energy Physics, Medical Imaging, Molecular Biology:
- Human Genome project gives the order of base pairs in our DNA- but does not tell us what proteins look like.
- Highly complex shapes (folded)- picture would be worth a lot!
- Optical microscopy- too small; SEM- too delicate; TEM- too much internal detail.



- Application! Use crystalline array of proteins, and X-rays to observe!

# Critical Step: RIE etching

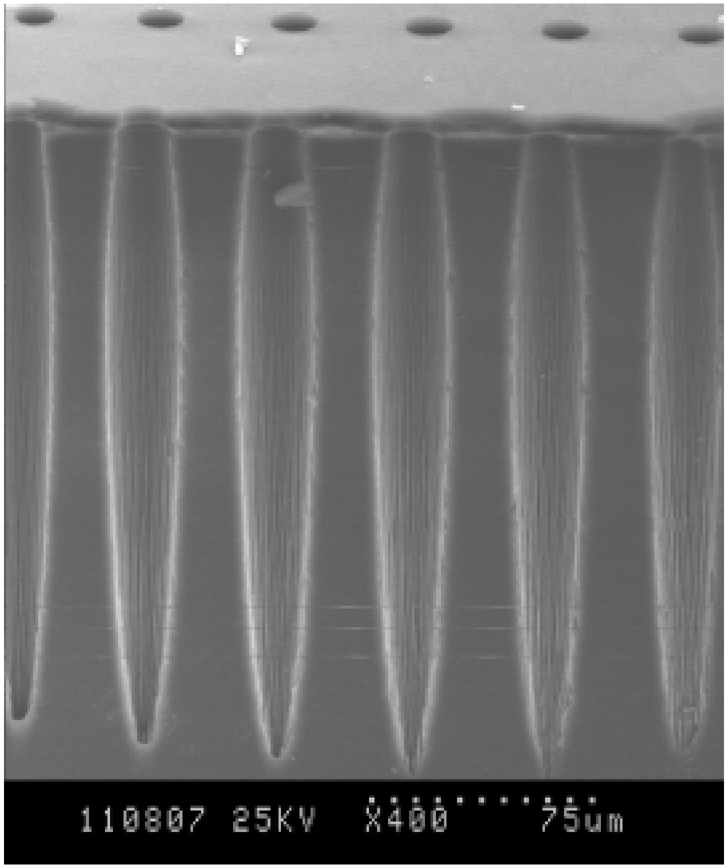
- In forming the 3-D electrodes, high aspect ratio holes are particularly important.



- Electrode channels represent detector “dead volume”.

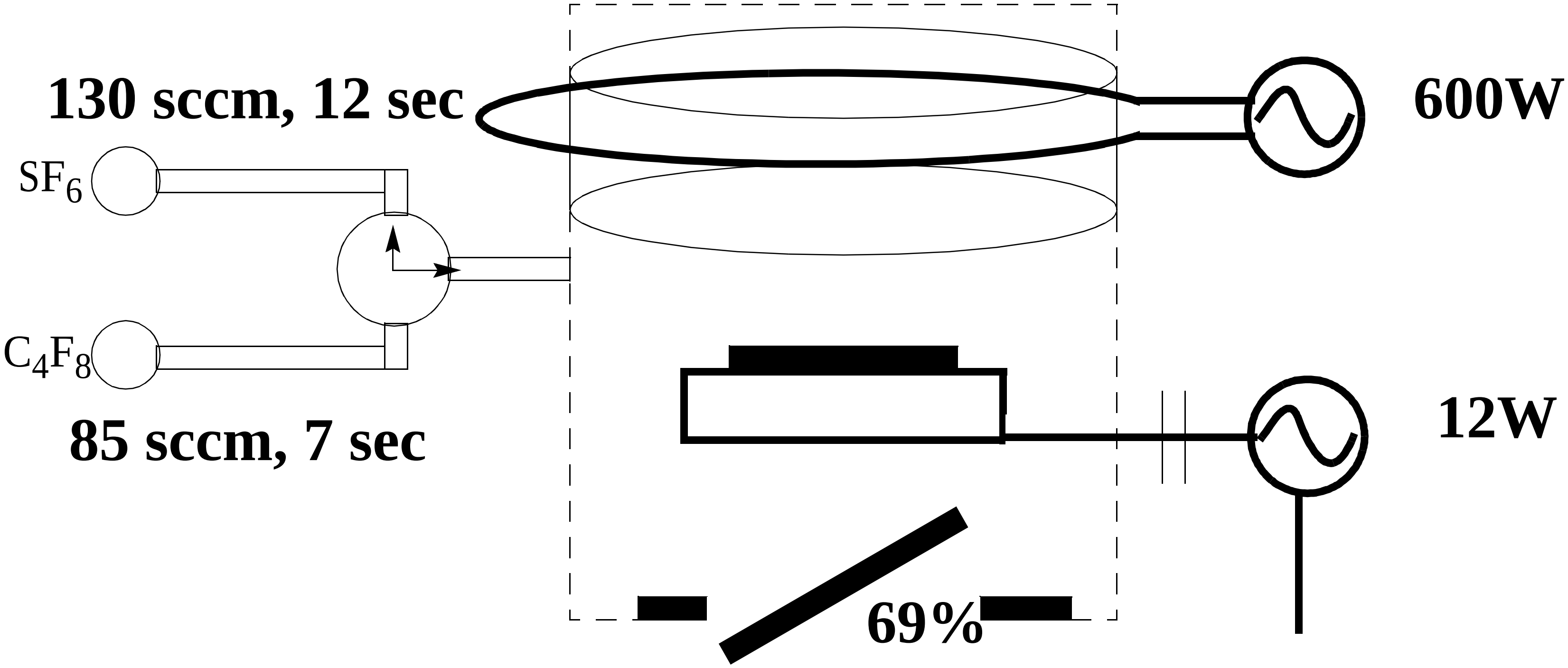
# STS “Deep” Recipie, Out-of-the-box

- Standard recipie:  designed for simple structures, fast, deep etch.



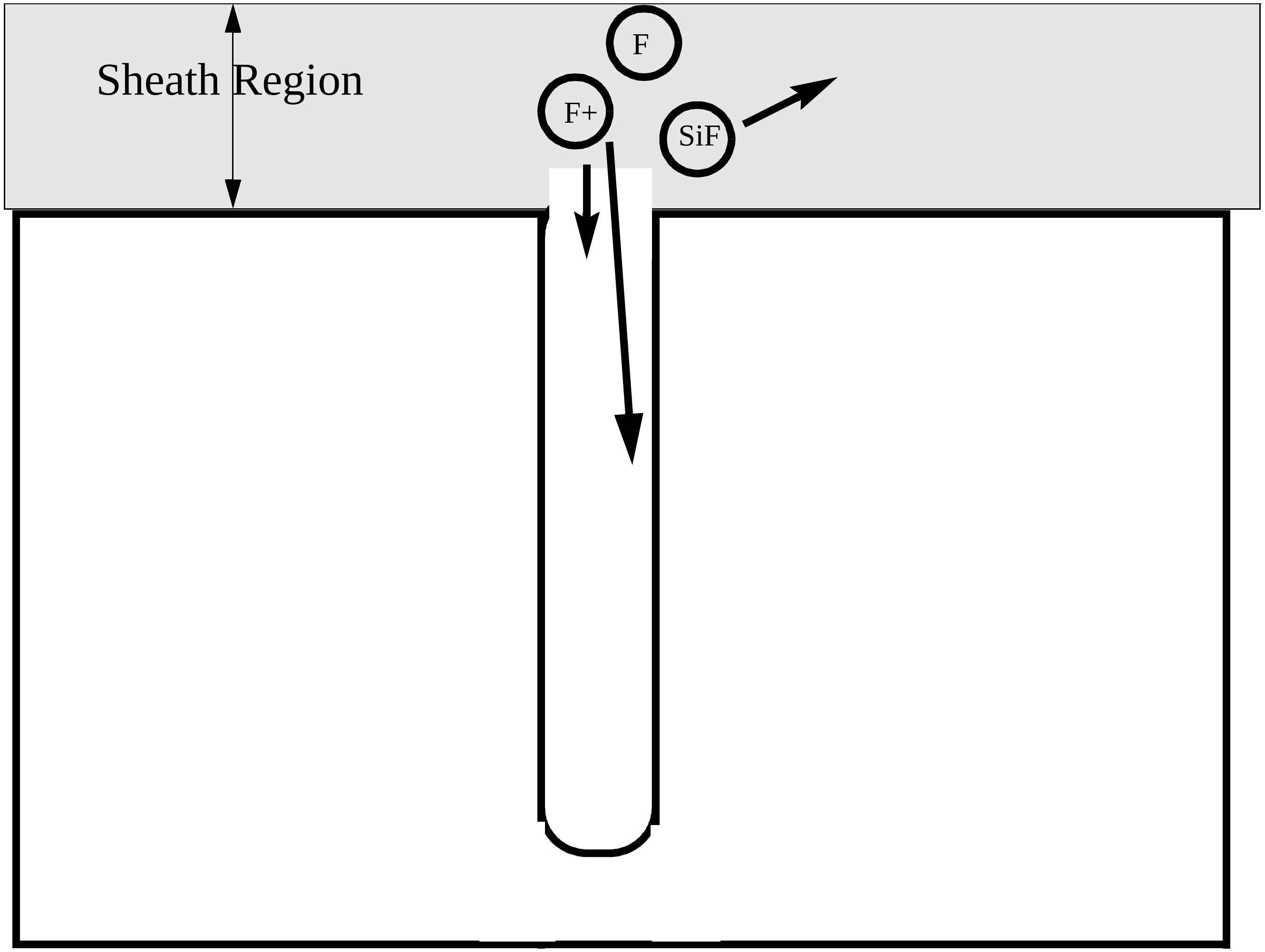
- Effective Aspect Ratio:  11:1
- (Effective aspect ratio is $\frac{((depth))}{(\text{AVERAGE diameter})}$ )

# “Deep” Etch Recpie



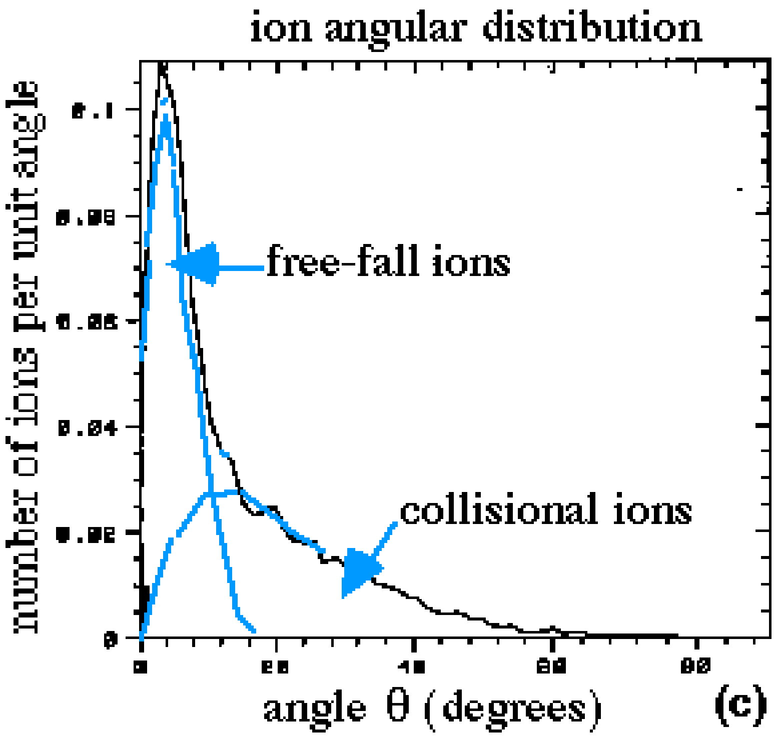
- Bosch Process
- Inductively Coupled Plasma

# Plasma Process: Limiting Factors in Ion Directionality



- Collisional Ions- pressure dependence
- Freefall Ions- Field dependence

# Improving Etch By Reducing Collisional Ions:

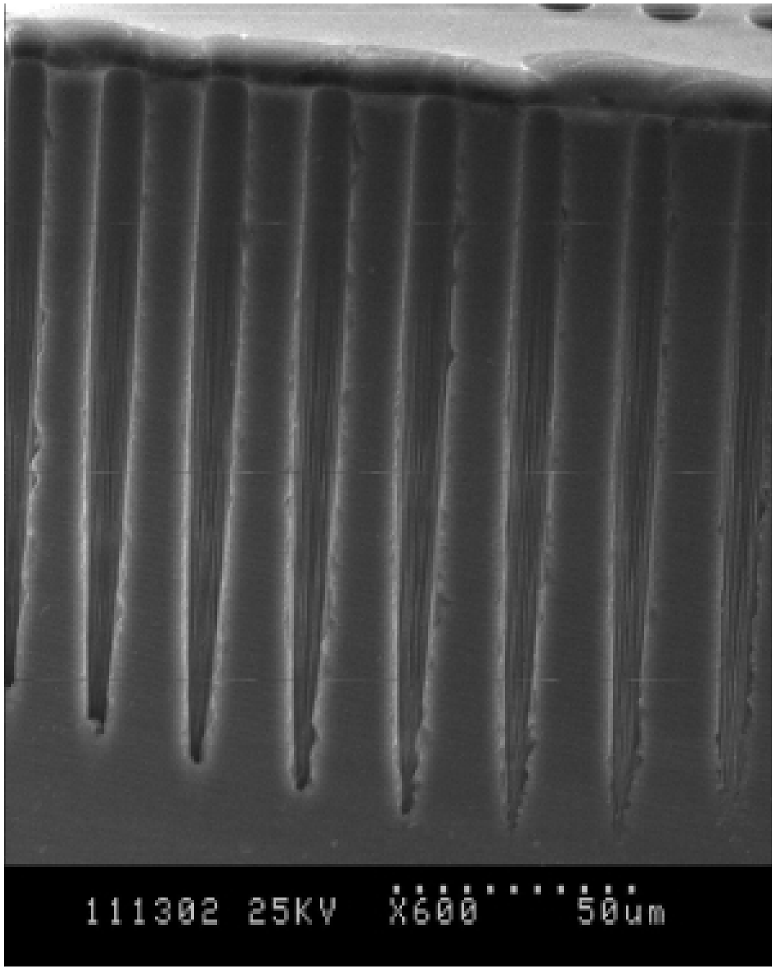


From McVittie

- Try Reducing Pressure to Reduce Collisional Ions in sheath:
- $K_D = \frac{\lambda_i}{S_o}$ (Ion Mean Free Path) (Sheath Thickness)
- Desire $K_D \geq 2$

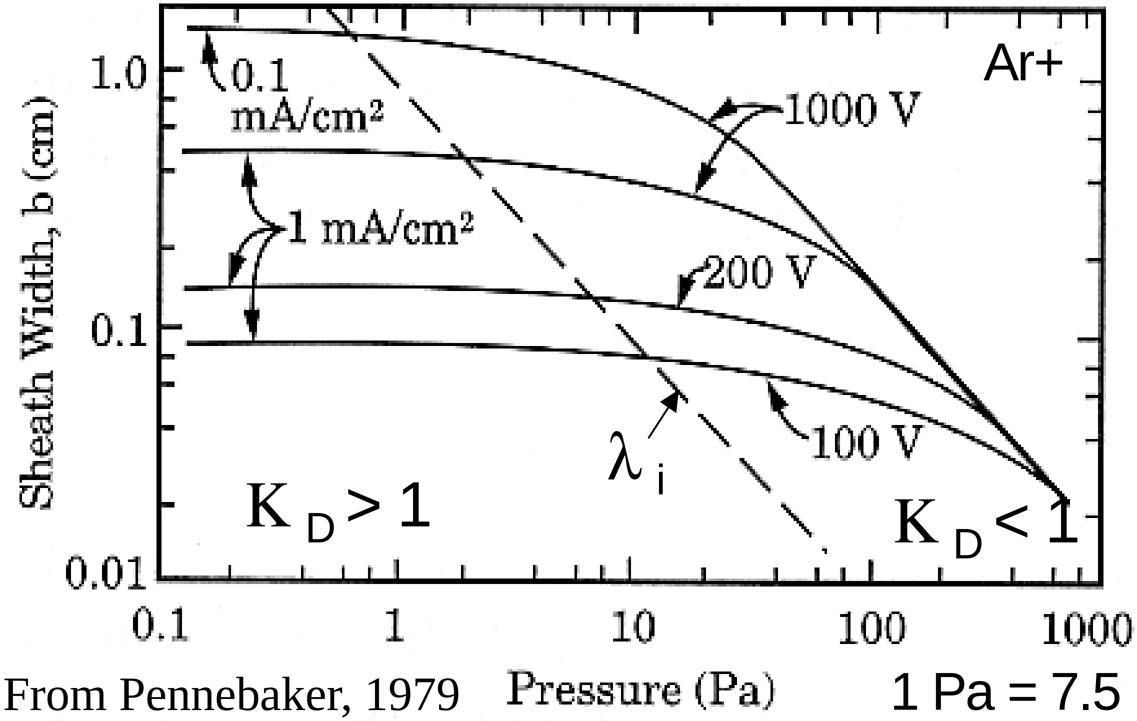
- Conclusion: At 40 mT, we’re probably near this transition (K~1 or 2)

# Result of Reduced Pressure



- Pressure reduced ~30%.
- Much reduced “bowing”.

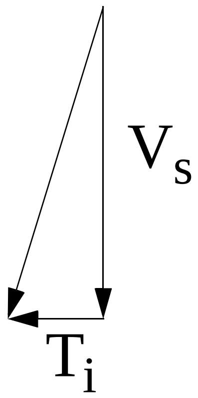
# Next Step: Sharpen Freefall Ion Angle



From Pennebaker, 1979

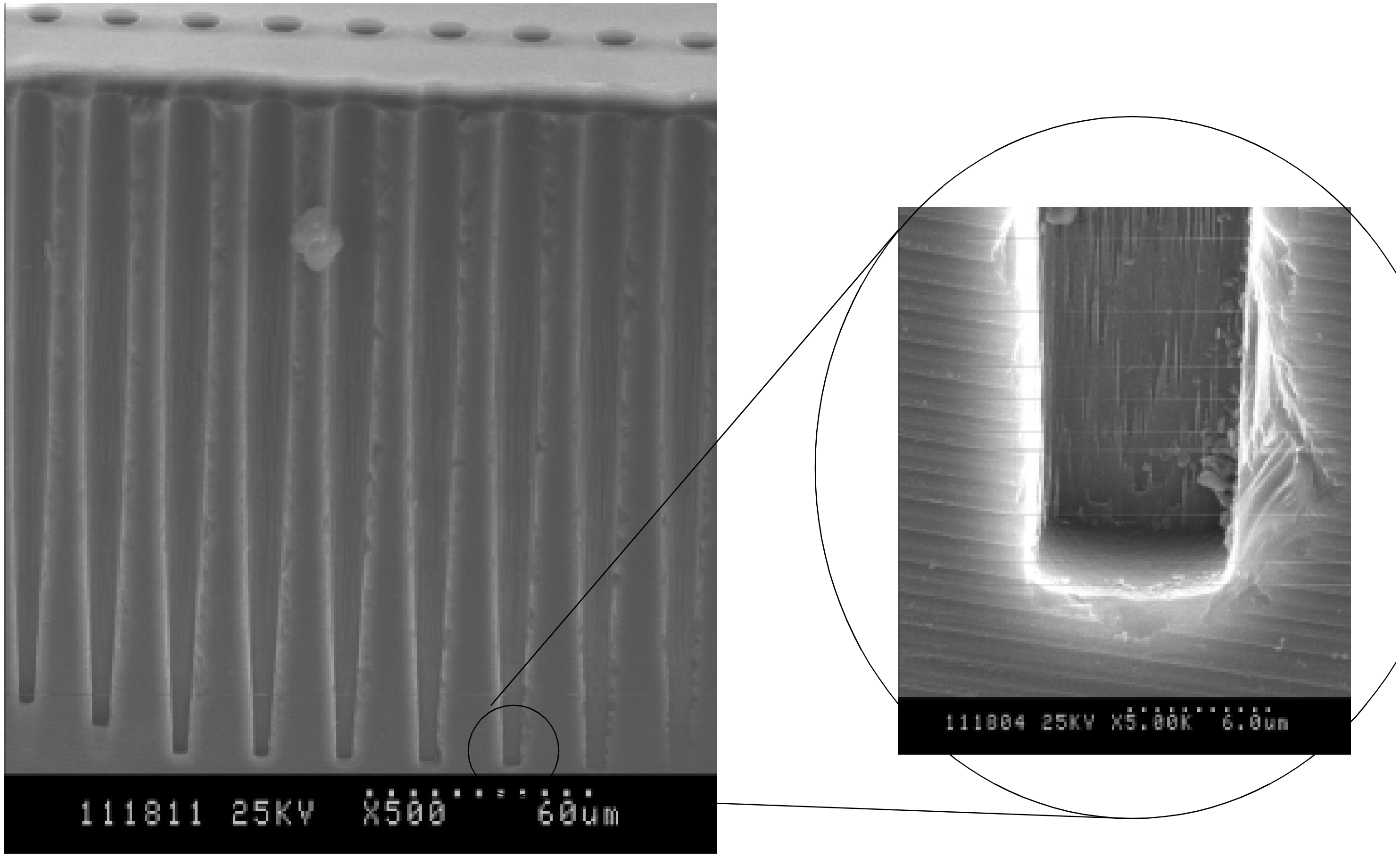
1 Pa = 7.5 mT

- Further reduction in pressure is useless
- Increase in Bias increases sheath thickness



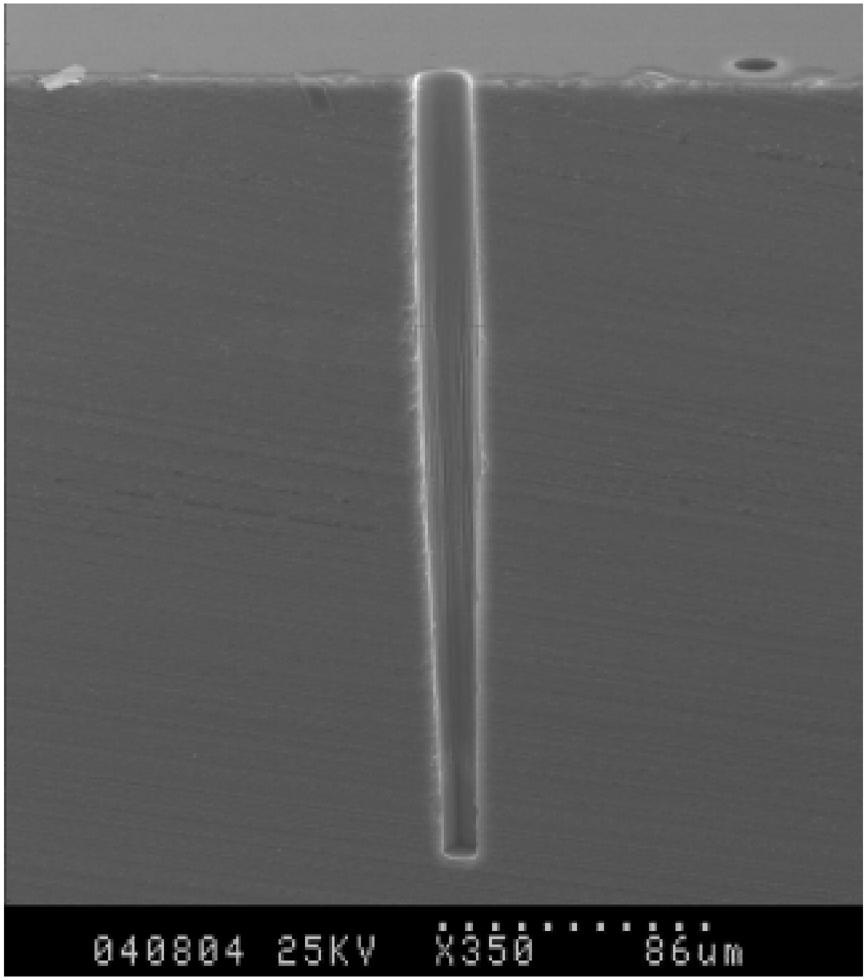
- Forget about mean free path, focus on sheath thickness for freefall ion directionality

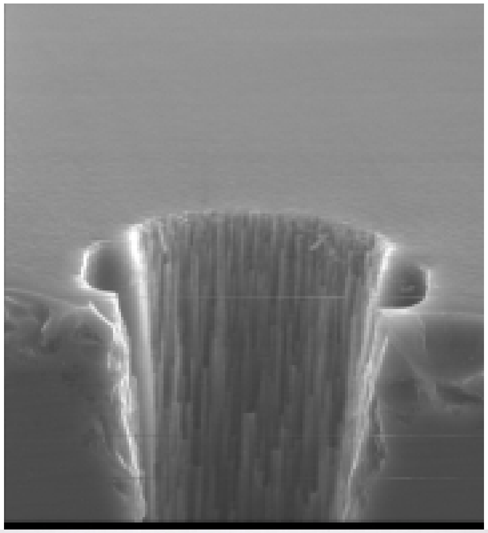
# Etch Results with Increased Bias

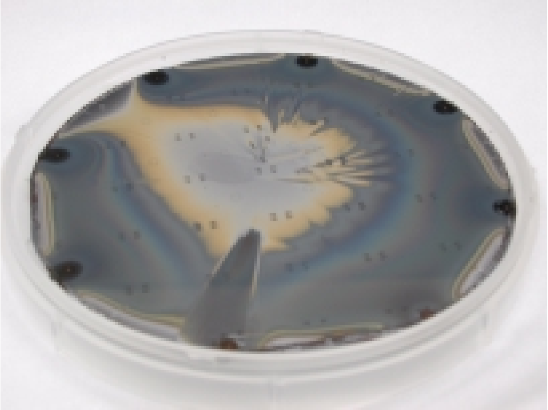


- Bias increase 10%
- Increased bias improves ion angle distribution.→Flat Bottoms!

# More Power!!







- Results are promising, but etch mask disappears much faster.
- Solvable problem.

# Conclusion

- Good radiation detectors need good deep RIE
- The physics and modeling of etching works! Experiment⇔Simulation
- Practical limits are reached with ion directionality
- Etch mask selectivity becomes problematic.

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