Gas Delivery and Virtual Process Chamber Concept for Gas Assisted Material Processing in Focused Ion Beam System

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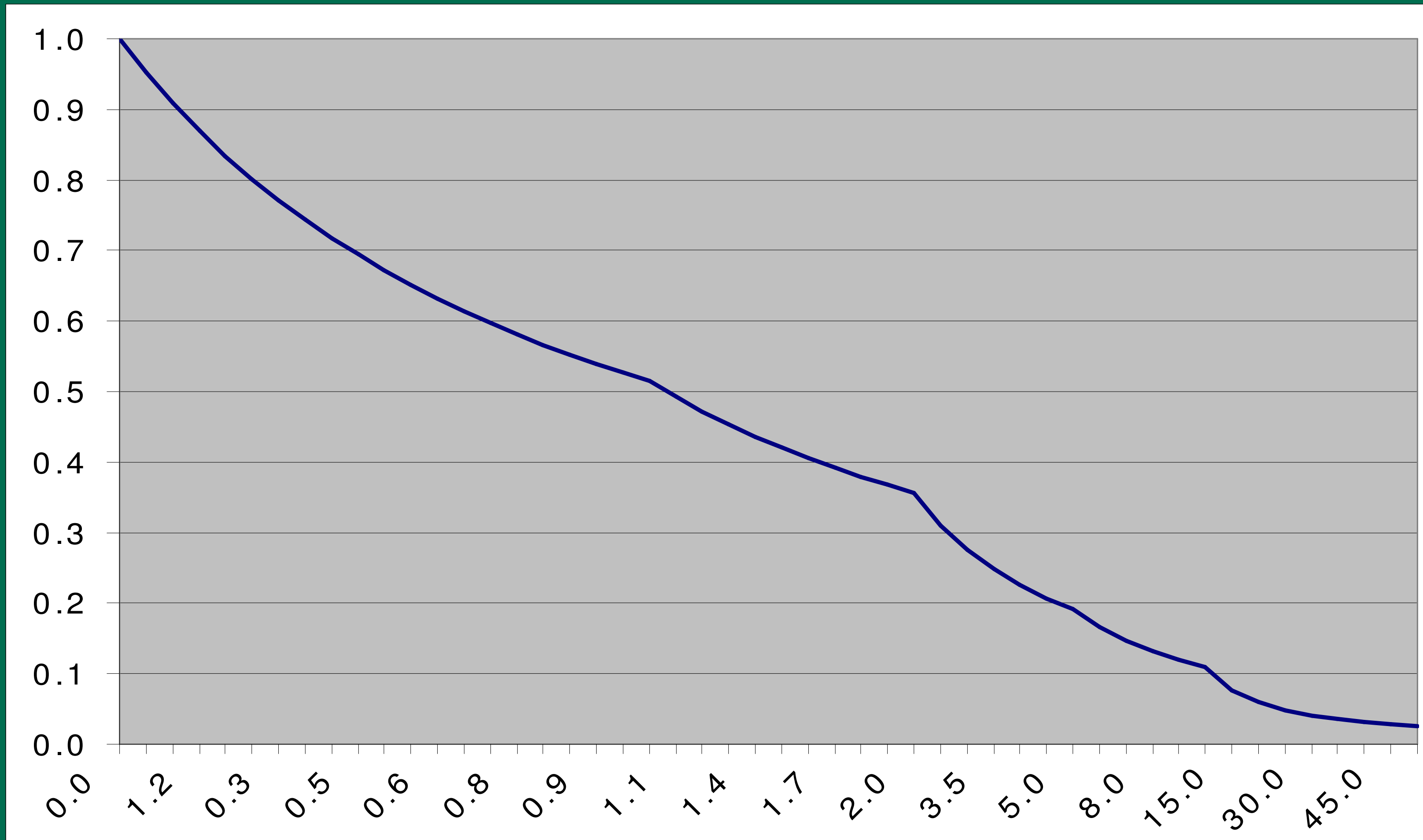
Gas Assisted Etching (GAE) Rate Versus Pressure Relationship in FIB GAE Process

- Optimal precursor gas pressure for Cl_2-assisted etching of GaAs by FIB is in 20 mTorr range.
- Optimal precursor gas pressure for XeF_2-assisted etching of Si by FIB is in 1 mTorr range.
- Etching rate with Cl_2 declines rather rapidly as pressure drops below or rises above the optimal.
- Results by Y. Ochiai et al., "Pressure and Irradiation Angle Dependence of Maskless Ion Beam Assisted Etching of GaAs and Si", J. Vac. Sci. Technol. B 3(1), 1985, pp. 67 - 70
- FIB systems operate at 10^{-5} Torr (or less) pressure level in main chamber (N. Bassom et al., "Modeling and Optimizing XeF2-enhanced milling of Silicon", Proceedings ISTFA 1999, p. 257).

Gas Delivery Within High Aspect Ratio (HAR) Via

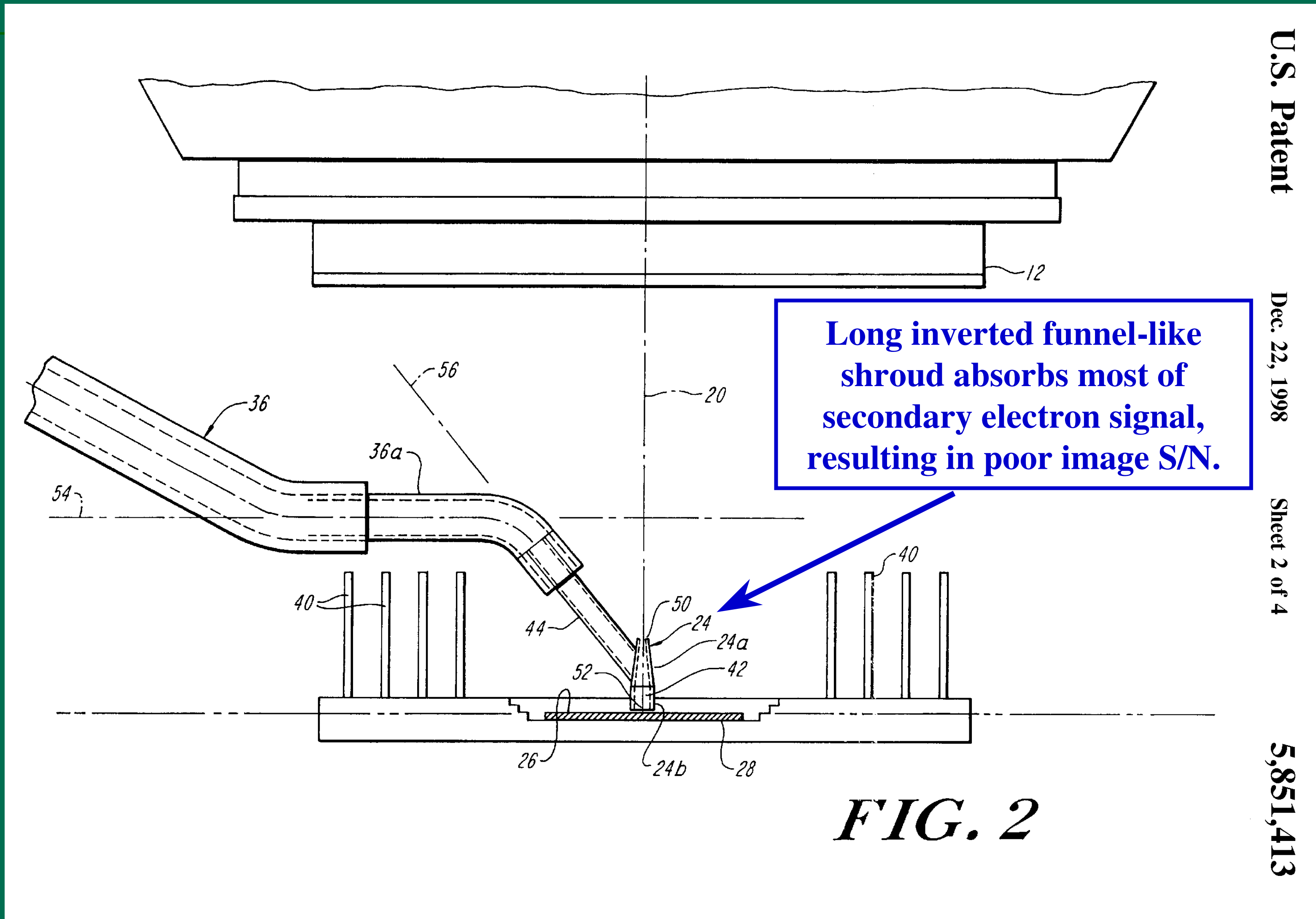


Plot of Ref. [1] data

Historical Methods of Gas Delivery in Focused Particle Beam Systems

- Hypodermic needles (J. Orloff, “Charged Particle Optics”, CRC Press, 1997, pp. 441 - 453, and elsewhere)
- Separately pumped gas-filled sample chamber (Y. Ochiai et al, “Pressure and Irradiation Angle Dependence of Maskless Ion Beam Assisted Etching of GaAs and Si” J. Vac. Sci. Technol. B 3(1) 1985)
- EBD cell with vapor source (A. Filch et al, “High-vacuum versus “environmental” electron beam deposition” J. Vac. Sci. Technol. B 14(4) 1996)
- “*Shroud*” or “*Beehive*” gas concentrator (Casella et al, 1998, US Patent 5,851,413 and Libbi et al, 2002, US Patent 6,497,194)

Limitations of *Shroud* (“*Beehive*”) Concentrator



Electrostatic Bias of Shroud Concentrator

- Introduction of shroud concentrator significantly reduces level of secondary electron signal available for detection.
- Experiments demonstrated that image contrast is improved by factor of eight by positive electrostatic bias applied to shroud ("*Beehive*") concentrator, however S/N remains low.
- Results by V. Ray et al., "Improvements of Secondary Electron Imaging and Endpoint Detection…" ISTFA 2003 Conference Proceedings, Santa Clara, CA pp. 338-342.

Effects of Vacuum Vessel Geometry on Gas Concentration

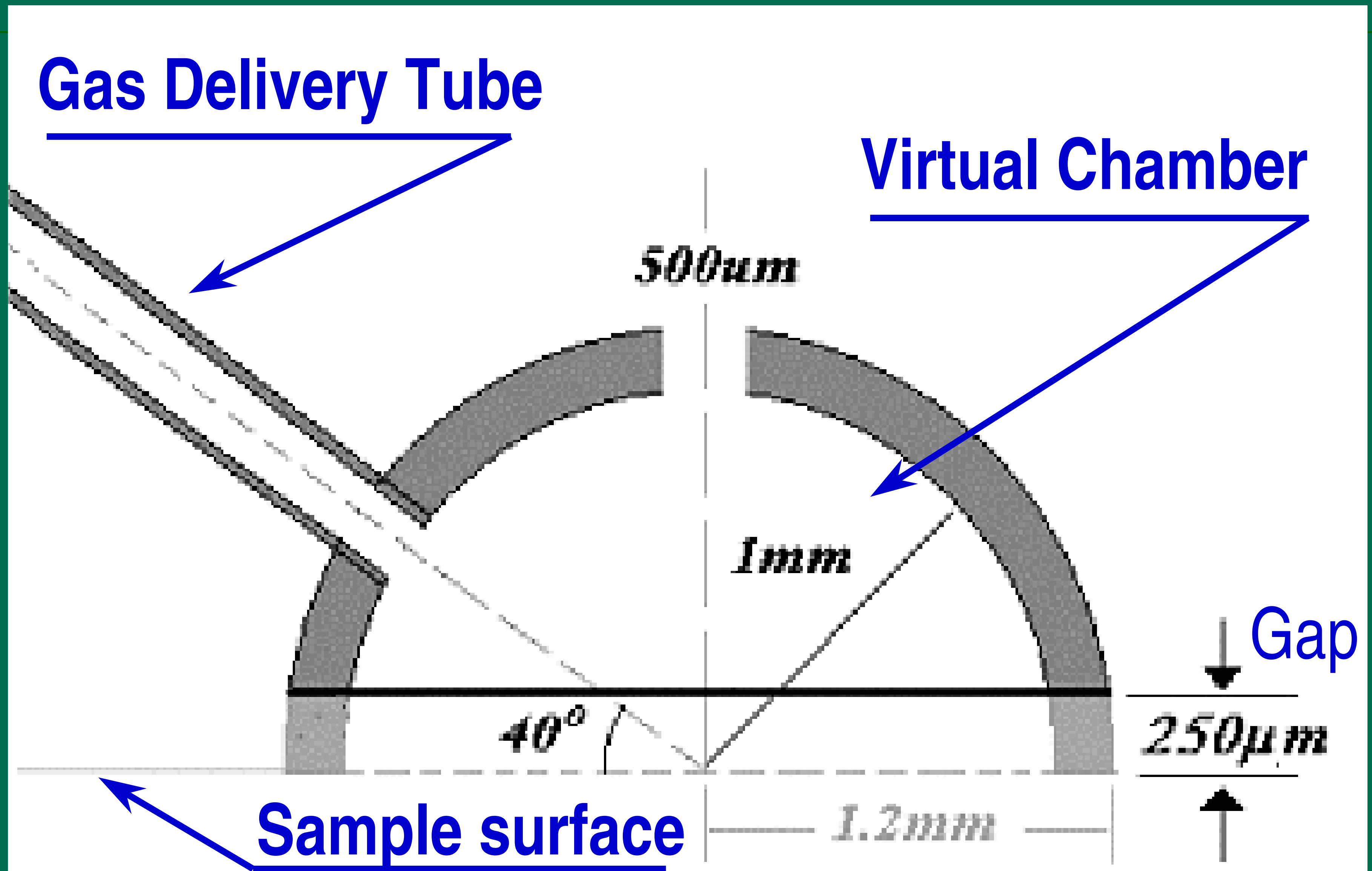
- Theoretical calculations predict localized gas concentration in the center of a spherical vacuum vessel by factor of seven larger then at the vessel walls.

- Attempt of experimental measurements of the distribution indicated uniform pressure distribution within the vessel.

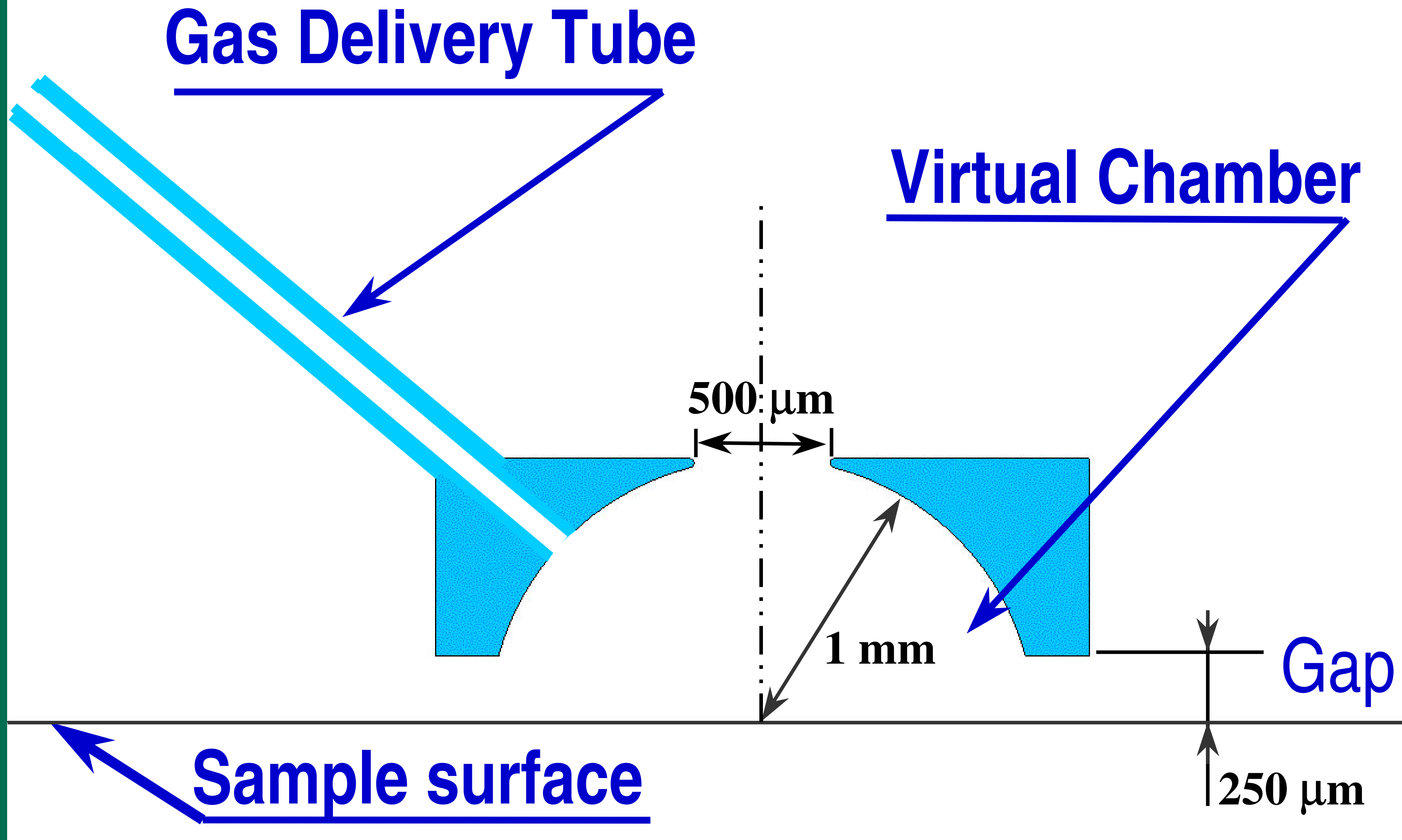
- Results by S. B. Nesterov et al., “Influence of the vacuum chamber shape on the non-uniformity of gas distribution”, Vacuum 53 (1999) pp. 193-196.

Virtual Processing Chamber Concept

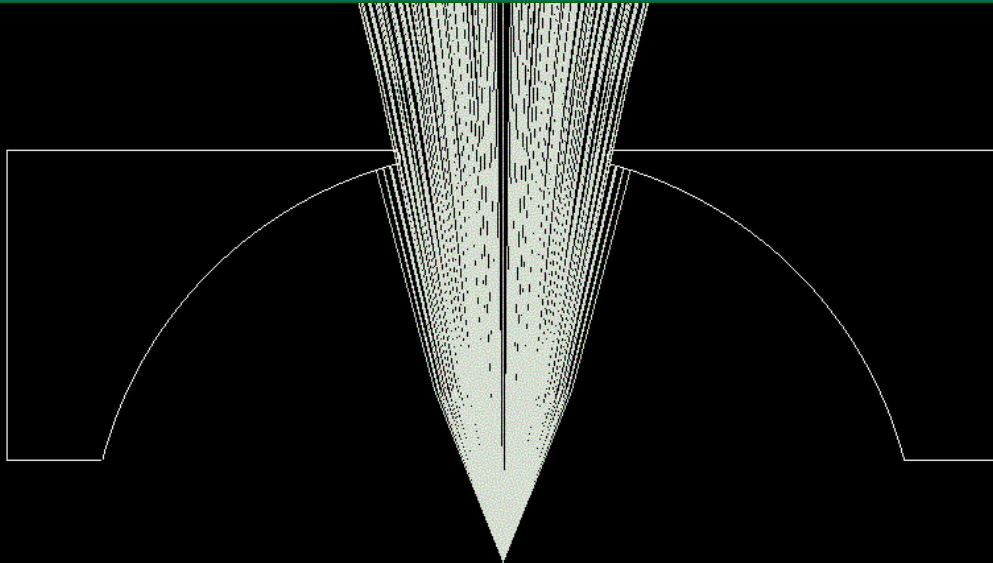
Image From the EIPBN 2004 Abstract



Proposed "*Cupola*" Nozzle



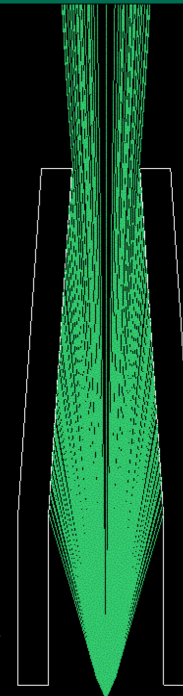
Electron-Optics Simulations of "*Cupola*" and "*Shroud*" or " *Beehive*" Nozzles



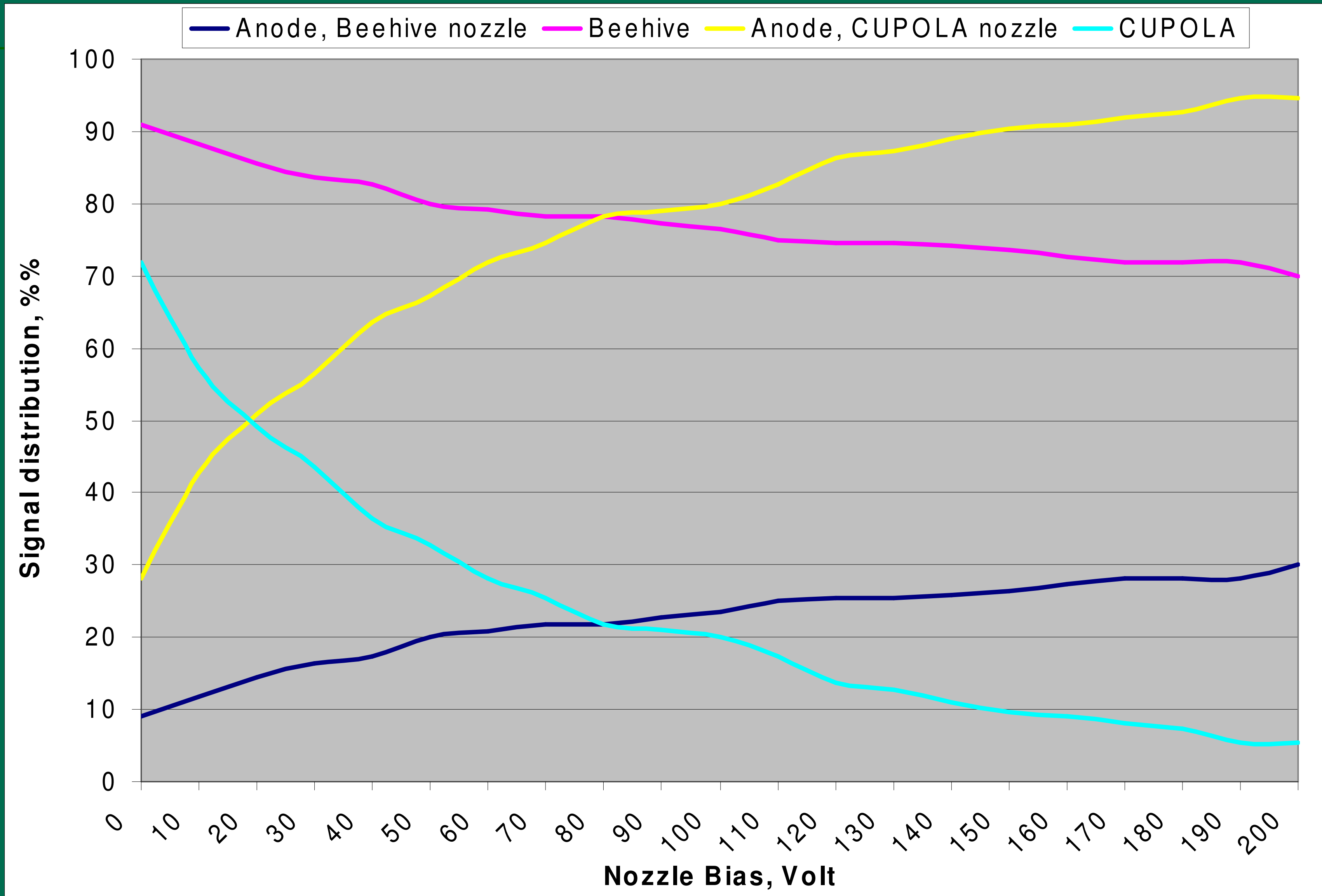
"Cupola" nozzle biased +200V transmits 94.5% of secondary electrons.

Same 2 mm width of bottom opening is simulated for both nozzles.

"Shroud" or "Beehive" nozzle biased +200V transmits 30% of secondary electrons.



Electron-Optics Simulations of "*Cupola*" and "*Shroud - Beehive*" Nozzles



Conclusions

1. Proposed virtual processing chamber concept and "*CUPOLA*" nozzle geometry provide viable advancement of gas delivery techniques for charged particle beam processing apparatus. The concept is equally applicable to Focused Ion Beam (FIB) and Focused Electron Beam (FEB) systems.

2. Secondary electron trajectory simulations of "*CUPOLA*" geometry suggest that ~80% of the signal could be extracted through the "*CUPOLA*" under 100V positive bias conditions, a X4 improvement comparatively to the existing "*Beehive*" nozzles.

3. Secondary electron trajectory simulations suggest that a significant fraction of the secondary electrons are absorbed by the gas delivery nozzles and set a basis for experimental investigation of possibility to monitor the nozzle current for the purposes of detecting material-dependent transitions in a secondary electron emission.

Ongoing and Future work

- 3D Simulations of "*CUPOLA"* nozzle, including reduced dimensions and effects of bias on primary ion and electron beams.
- Technology suitable for manufacturing of "*CUPOLA*" nozzle geometry? Micro-machining, electroforming, laser, or FIB processing?
- Experimental monitoring of nozzle current during the milling of HAR via could be of high practical interest for detection of material-dependent transitions in secondary electron emission.

REFERENCES

- 1. J.F. O'Hanlon "A Users Guide to Vacuum Technology" John Wiley & Sons, 1989.
- 2. J. Orloff, M. Utlaut, L. Swanson "High Resolution Focused Ion Beams, FIB and Its Applications" Kluwer Academic Publishers, 2003.
- 3. Casella et al., US Patent 5, 851, 413 "Gas Delivery Systems for Particle Beam Processing", 1998
- 4. Other publications as referenced throughout the presentation

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