Controlling Energetic Neutral Beams Produced from Inductively Coupled Plasmas for Material Processing

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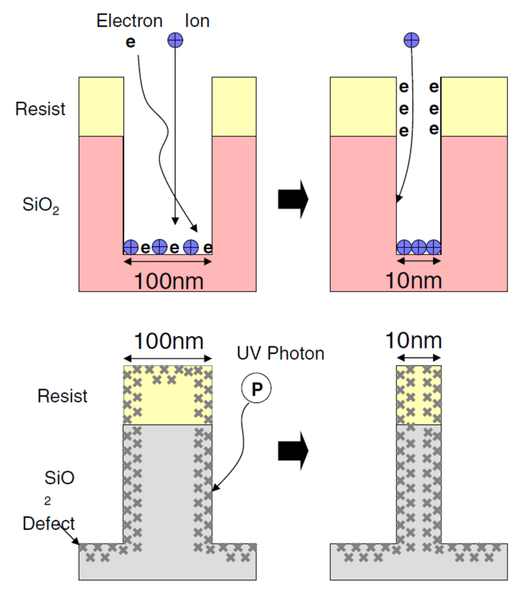
Motivation

- **Plasma etching** and **deposition** are essential for microelectronics fabrication, requiring **precise** control of ion **energy and angular distributions (EADs)** hitting the wafer to enable critical surface reactions.
- However, **plasma processes** can negatively impact **electrical** and **optical** properties of nanodevices due to:
  - **(1) Differential charging of features** - distorts ion trajectories leading to defects (e.g. bowing) or ARDE.
  - **(2) UV photons** - can cause surface defects (dangling bonds).
- These effects should become more pronounced as device dimensions shrink, especially in **2-dimensional devices** with near monolayer thickness.



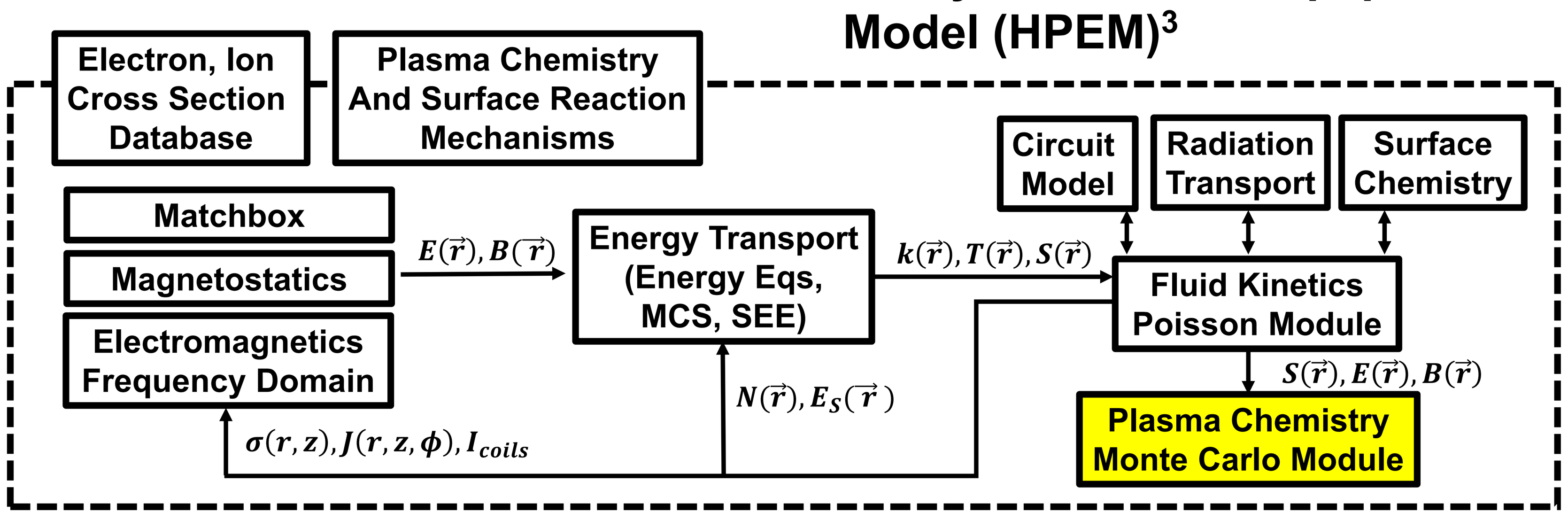
Impact of Differential Charging (top) and UV exposure (bottom) on nanoscale devices as feature sizes decrease.[1]

- **Energetic neutral beams** offer a potential **damage-free** alternative for nanoscale fabrication[2].

How can we control and optimize the energy and angular distribution of neutrals hitting the wafer?

Modelling Tool

2D Hybrid Plasma Equipment Model (HPEM)[3]



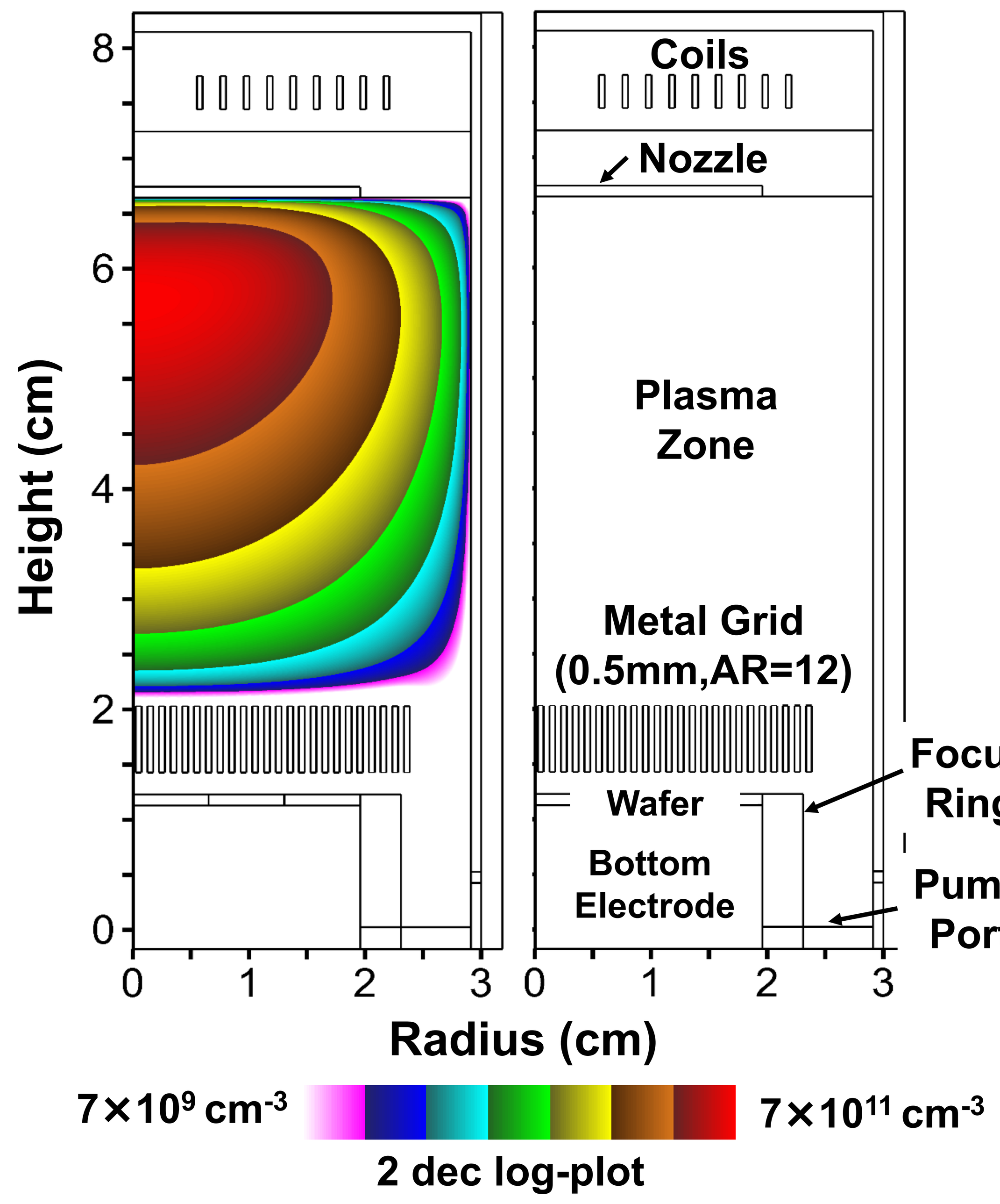
- **HPEM** is a simulation tool which combines **kinetic** and **fluid** methods to model the physical and chemical behavior of **low-temperature plasmas**.
- **The Plasma Chemistry Monte Carlo (PCMC) module** uses source terms and electric/magnetic fields from HPEM to launch and track ion and neutral particles until they hit a surface.

Neutral Beam Reactor Geometry

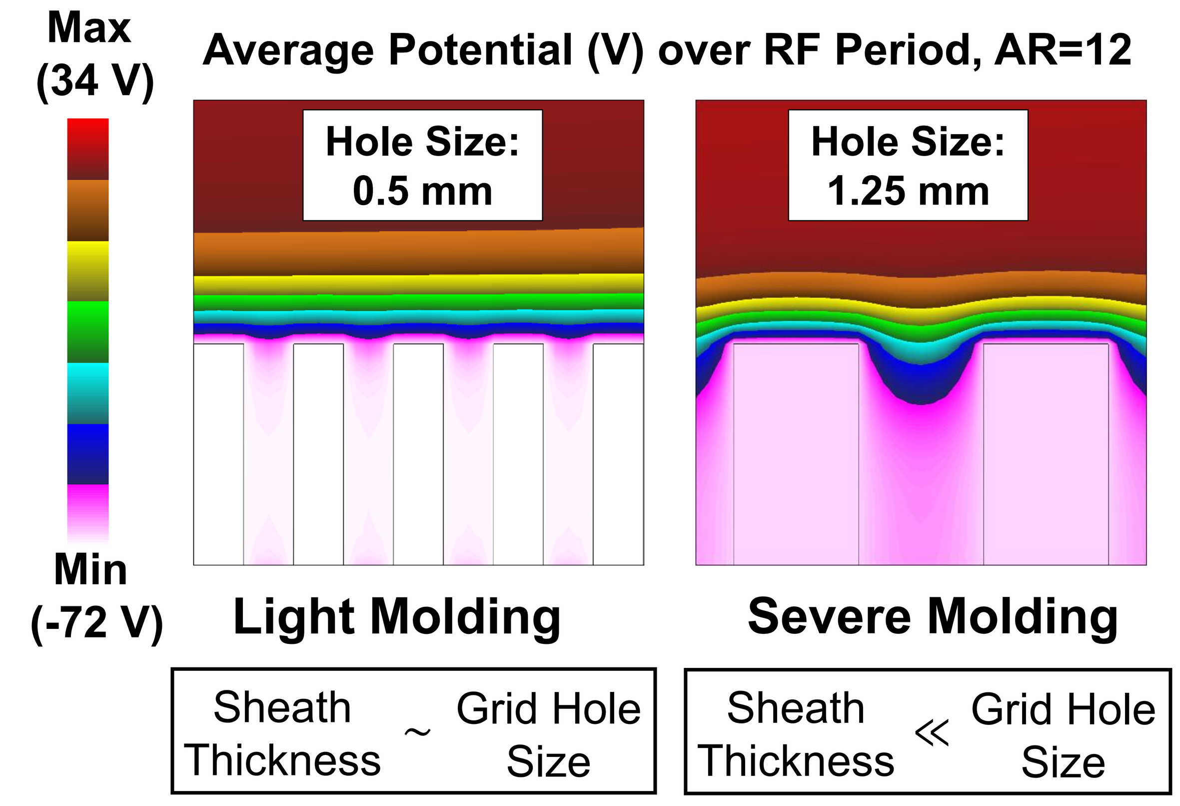
- **Neutral beams** can be generated by **accelerating ions** toward a **biased grid**, where they **reflect** and **neutralize** on the aperture walls.
- **HPEM** has been improved to model **ion reflection** from the grid, enabling the calculation of **energy and angular distributions of the neutrals** hitting the grid.

- **Inductively Coupled Plasma** (ICP) at **50 W**.
- **Argon** at 20 mTorr and 400 K.
- **Metal grid** with **RF bias:** 100 V, 10 MHz.
- Bottom Electrode grounded.
- Variable **Grid Hole Size** (0.5-1.25 mm) and **aspect ratio** (6-24).

- **Assumptions**:
  - (1) Charge-exchange reactions are not considered.
  - (2) All argon ions reflect **elastically** and **specularly** from the grid as ground state neutrals.



Effect of Plasma Molding



The degree of **plasma molding** over the grid holes influences the ion trajectories[4].

↓

Severe plasma molding favors **stronger ion deflection** toward the grid.

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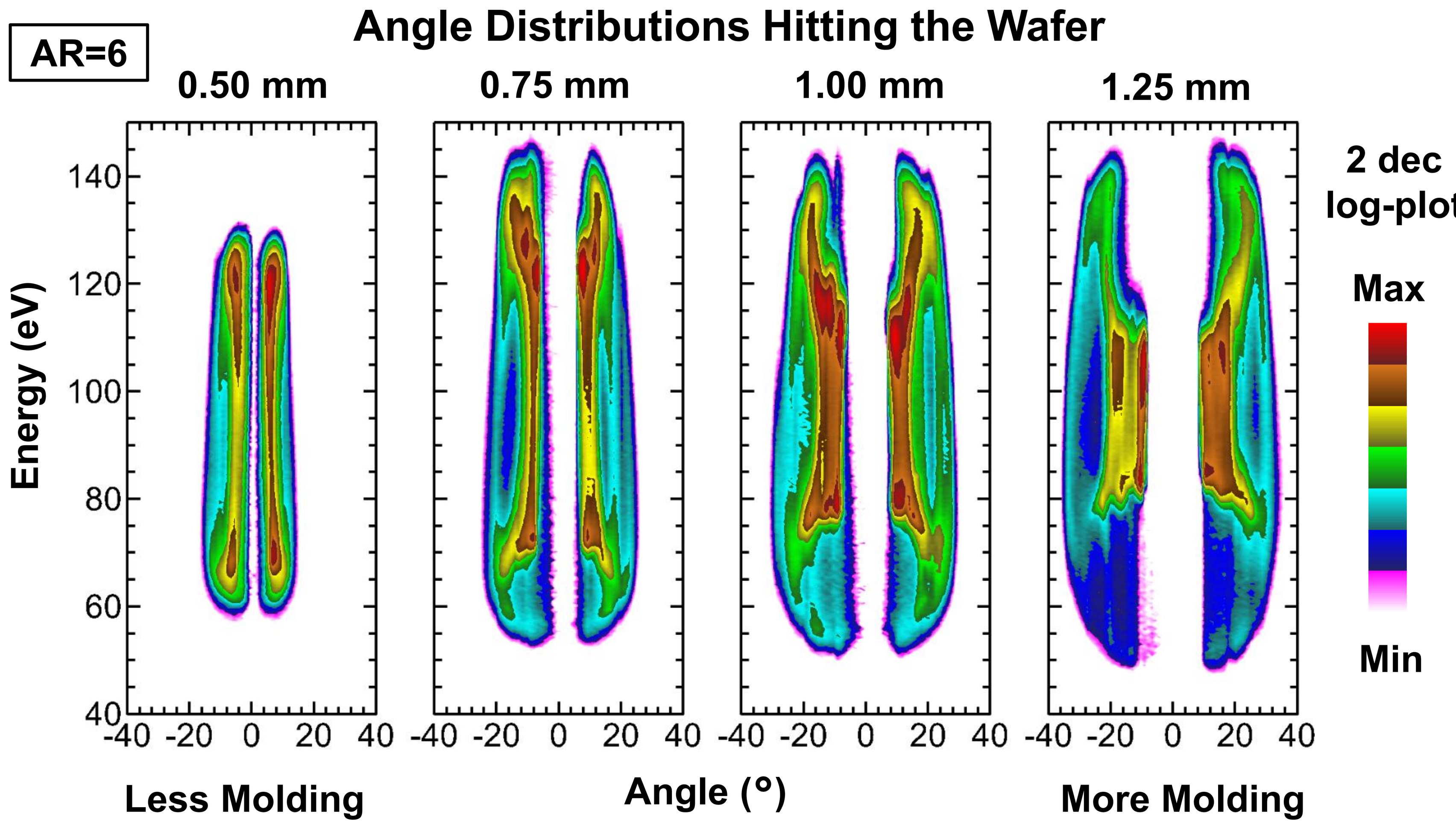
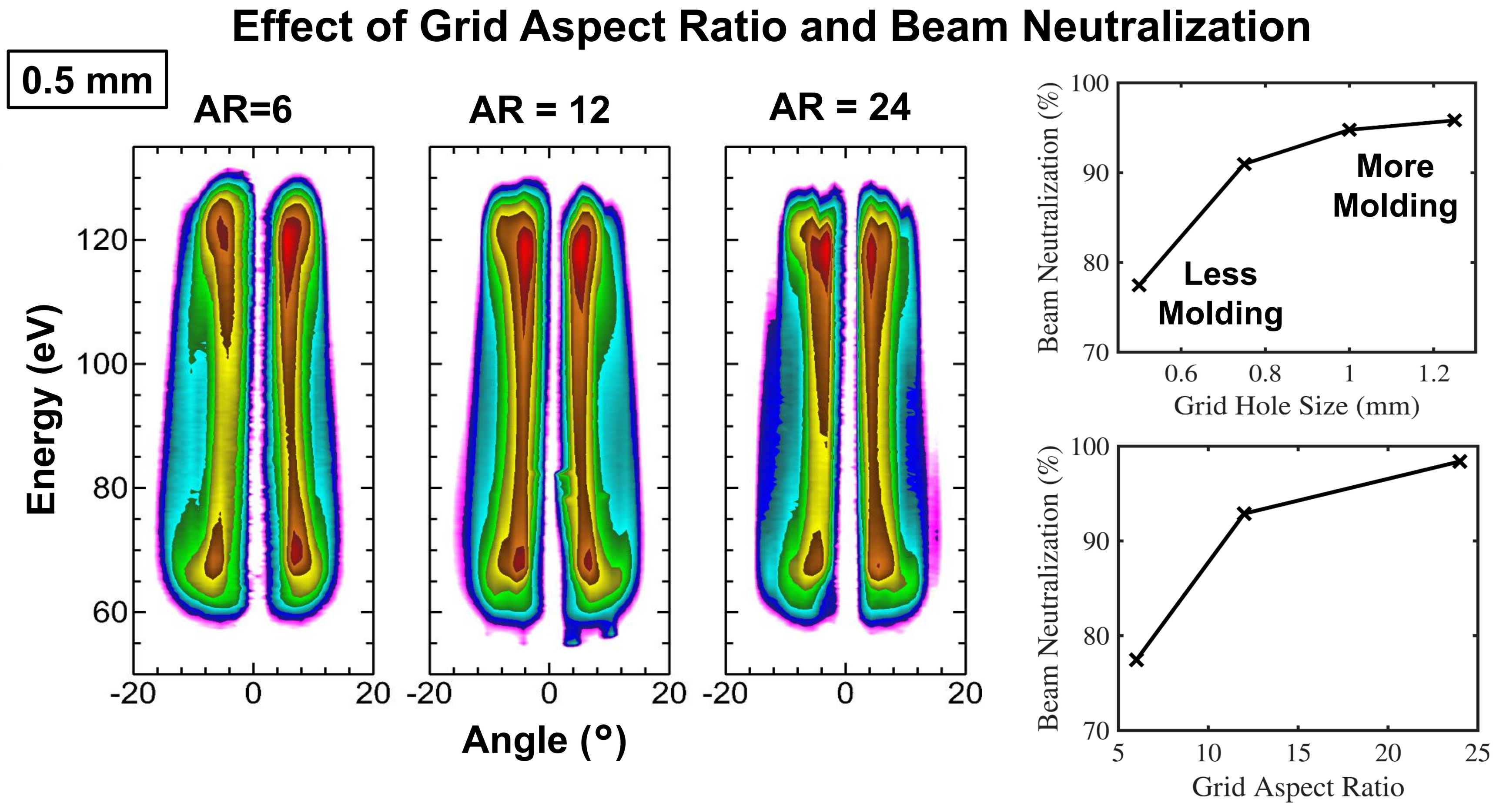
Higher neutralization but reflected neutrals hit grid with **larger angles**.

Effect of Grid Hole Size on the Neutral Energy and Angle Distributions Hitting the Wafer



- Few neutrals at very small angles (ions must be deflected to collide with grid).
- **Lighter molding** leads to **angularly-narrow distributions** and **severe molding** to **broader distributions** with **complex shapes** (curved sheath).

Effect of Grid Aspect Ratio and Beam Neutralization



- Varying **aspect ratio** does not change the distribution function significantly (plasma molding is a local phenomenon).
- **Beam neutralization** is **lower for lighter molding** but can be **increased independently** by increasing **the grid aspect ratio**.

Summary

- In principle, neutral beams with **tunable energy and angular distributions** can be achieved while maintaining **high particle fluxes** ($\sim 10^{15}-10^{16}$ $\mathbf{cm^{-2}\ s^{-1}}$).
- **Plasma sheath molding** plays a key role in defining the distribution functions and can be controlled by adjusting the **grid aperture** and/or **plasma parameters**.
- To achieve an optimal **narrow-angle hot neutral distribution**, the grid geometry and operating conditions should be tuned to obtain **light sheath molding**.
- **Beam neutralization** can be improved by increasing the grid **aspect ratio**.

References

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