Motivation
Dual-frequency drives have been used to independently control ion density and average ion energy. It is natural to extend this idea using three frequency drives. The high frequency controls the ion density and the two low frequencies control the spread and the mean of the ion energy distribution.

Simulations have been done with regards to multiple frequency. A model has been developed to predict the IED from the voltage at the sheath. Ions see a filtered voltage at the sheath which gives rise to different magnitudes of the IED depending on how long ions spend at that energy. Collisions and fast neutral generation play important roles in processing and will be investigated.

Description of Model
• Sheath voltage $V_s(t)$ is from particle-in-cell (PIC) simulations
• Fourier transform $V_s(f)$
• Determine filter function $F$ for low frequency
  $1/t$ for high frequency
• Apply filter to $V_s(f)$ to get $V(t)$, the voltages ions respond to
• Inverse Fourier transform $V(f)$ to get $V(t)$
• Determine IED from $V(t)$
• Ions do not collide with neutrals
• Argon gas
• 1-D planar capacitive discharge model
• Example of 400 V at 64 MHz, 800 V at 2 MHz

Synthesis of Waveform
• Shown here are the graphs of the 400 V/64 MHz and 800 V/2 or 8 MHz IEDs
• Cumulative Distribution Function (CDF) of IED (denote by $F^*(E)$)
  • $F$ is the shape of the waveform needed as a function of arbitrary cycle length
  • To create a continuous waveform, mirror the shape of $F$
  • Determine the inverse filter with frequency desired (not shown)
  • Apply the inverse filter to determine the input voltage (not shown)

Collisions and Neutral Energy Distribution
• Fast neutrals are generated from charge exchange with incoming ions in the sheath
• Currently assume neutrals hit the wall immediately without other collisions
• Reasonable when the mean free paths are large compared to the sheath width
• Graphs show more ions are scattered and more neutrals are generated at higher pressure due to the increased charge exchange

2007 Main Objectives
(Lieberman) (PLAS Y4.1)
• Determine substrate ion energy distributions in multi-frequency capacitive discharges using kinetic simulations. ION energy distributions are key input to feature profile simulation, controlling sidewall scattering, micro-trenches and feature bowing. A key step in this work is to develop a method to quickly translate RF sheath voltages into ION energy distributions.

The Problem
• Forward Filtering
  $\text{ILD}(\omega) = \sum_{k=0}^{\infty} F(\omega) \delta(t-kT) = \frac{1}{\tau c}\int_0^\infty e^{-x} (1-\cos{x\tau p}) dx$
  • $\Delta t = 1/65536$ MHz
  • $\Delta t = (2 MHz - 1)/65536$

Future Goals
• Transfer results to profile simulations
• Synthesis of desired IEDs
• Address issues of ion-neutral collisions in the sheath and fast neutral generation with improved collision models

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