Ion Energy Measurements in a CCP with a Tailored Voltage Waveform Bias

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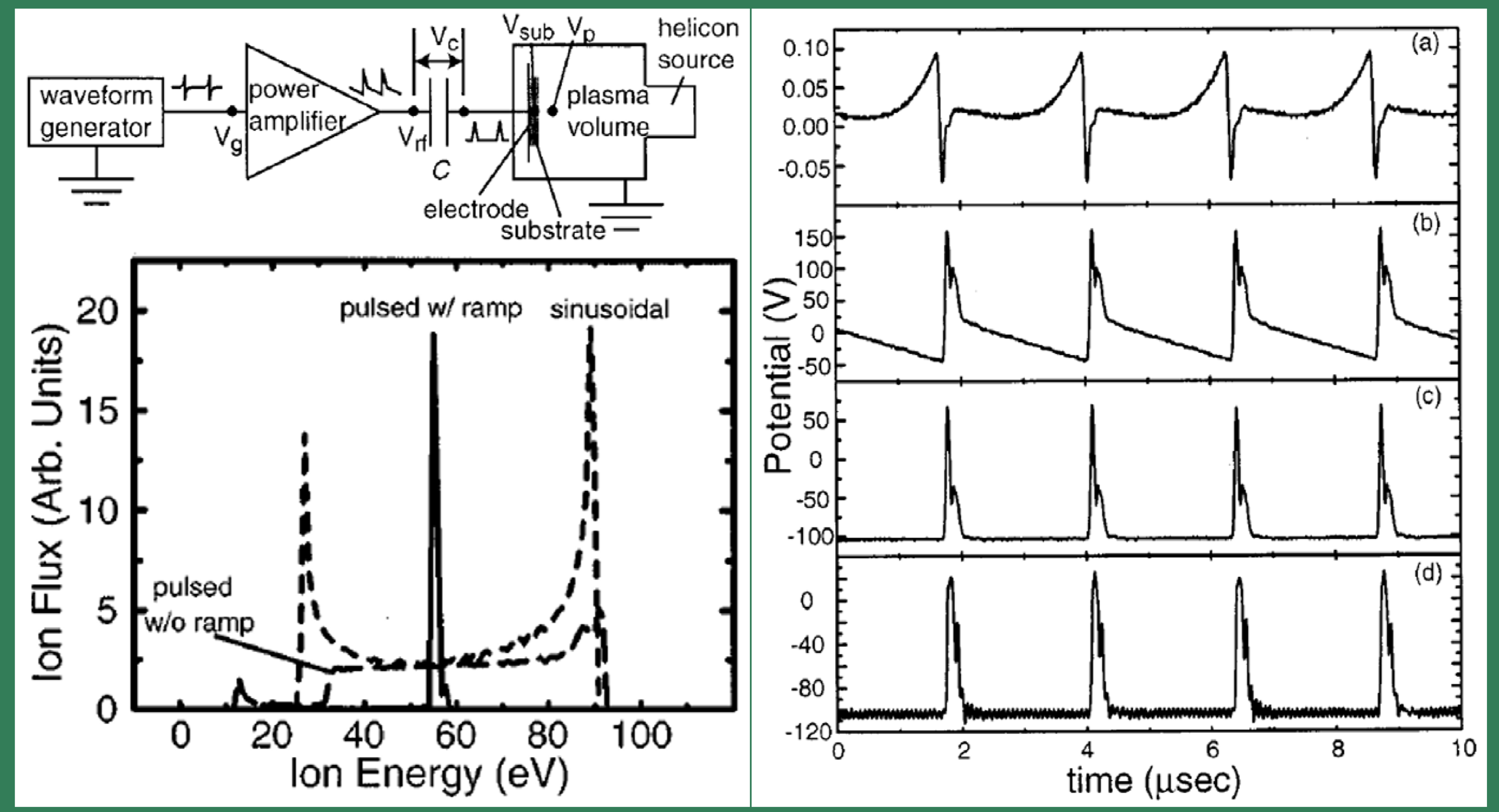
EAGLE HARBOR TECHNOLOGIES

Introduction

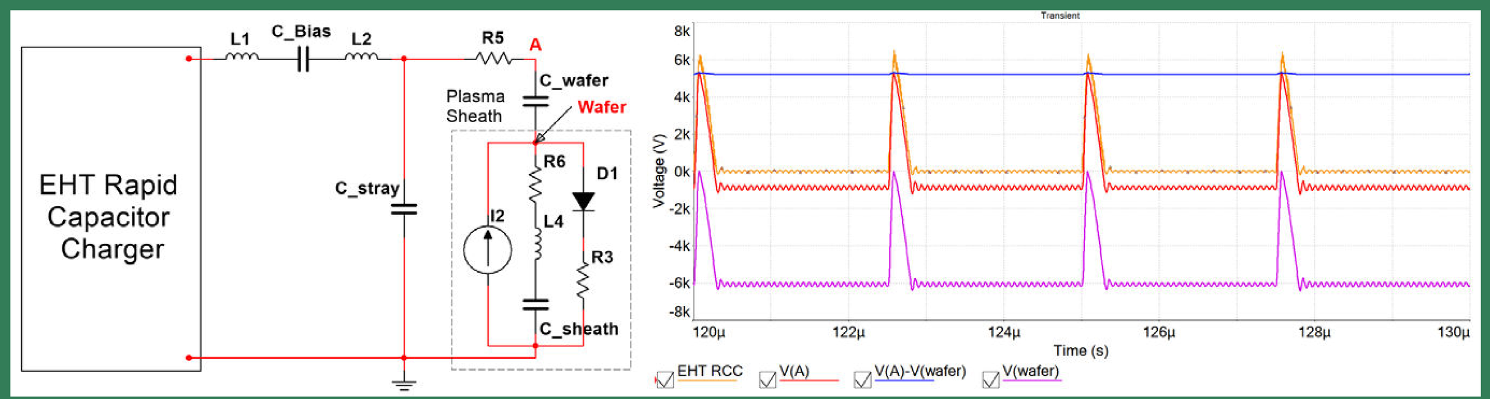
Using plasma etching to produce high-aspect-ratio (HAR) features is becoming increasingly important as the market demands solid-state non-volatile memory storage. To minimize bowing and twisting defects in HAR features, precision control of the ion energy distribution (IED) is required. Eagle Harbor Technologies (EHT), Inc. converted the experimental test chamber from an inductively coupled plasma source to a capacitively coupled plasma source that is now driven by a 60 MHz radio frequency generator. The bias tailored voltage waveform is produced by EHT Rapid Capacitor Charger that can charge capacitance to high voltage in tens of nanoseconds and operate at 400 kHz. EHT will present the chamber modifications, electron temperature and density measurements made with Langmuir probes, and IED measurements made with a retarding field energy analyzer. Based on these measurements, the next steps will be discussed.

Background

Wang and Wendt used a periodic bias waveform applied to the wafer electrode with a ramp rate determined by the ion current density (*I*) and the capacitance (*C*) such that $I = C\, dV/dt$. These pulses produce a very flat voltage on the wafer, which generates a very narrow IED. To handle the megawatt class peak power levels for industrial process, EHT modeled using our Rapid Capacitor Charger (RCC) to produce similar waveforms.



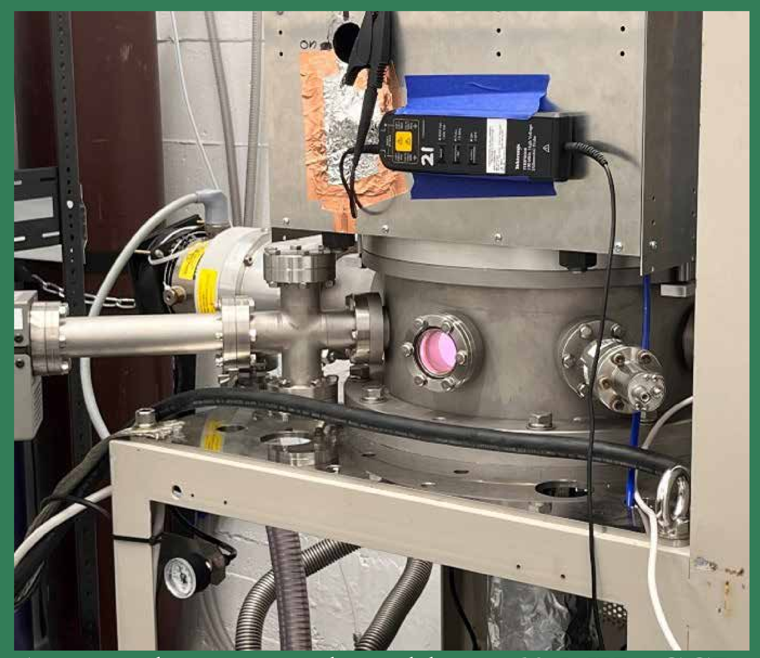
Clockwise: Top Left: Schematic of Wang and Wendt experiment. Right: Measured voltages: (a) waveform generator output, V_g (b) power amplifier output, V_{rf} (c) electrode voltage, and (d) voltage on surface of substrate, V_{sub}. Bottom Left: IED resulting from three different voltage bias waveforms.



Left: Circuit diagram of EHT RCC with plasma load. Right: RCC SPICE modeling of wafer voltage: EHT RCC output voltage (orange), voltage at point A (red), voltage at the wafer (magenta), and the voltage across C_wafer ($V_A - V_{wafer}$ (blue)).

EHT Plasma Chamber

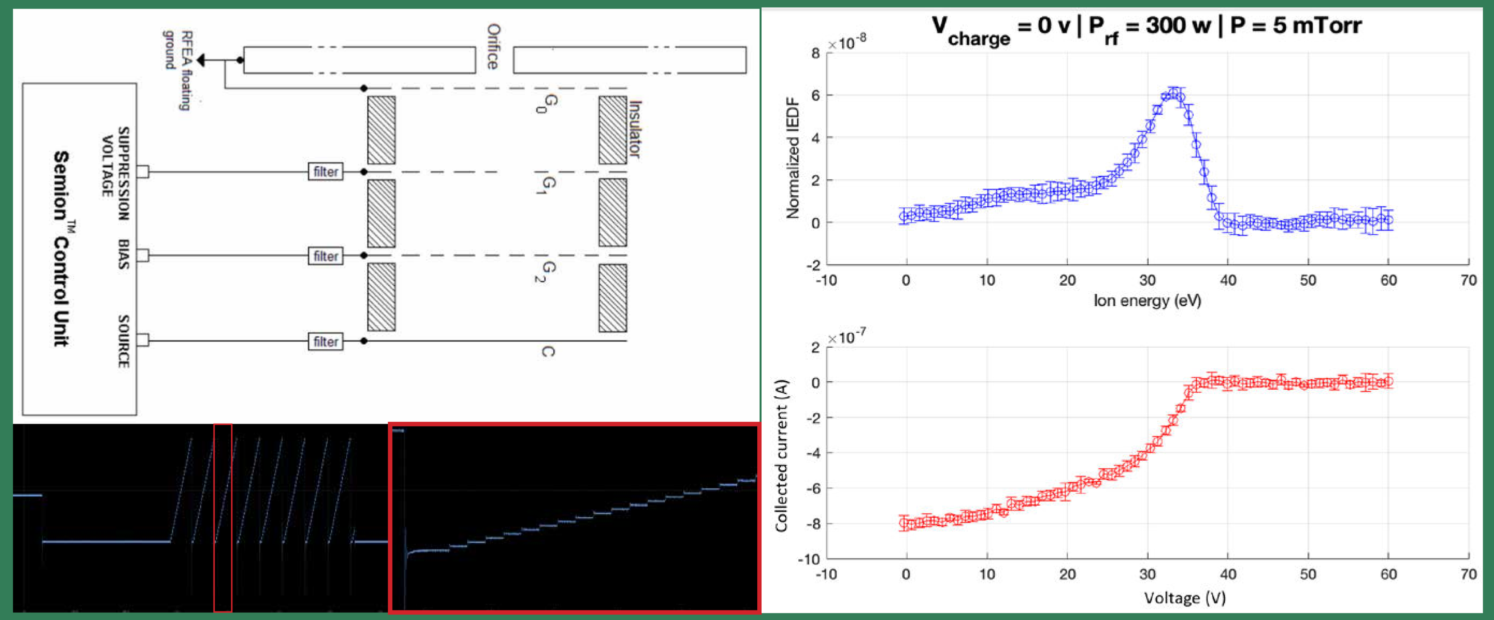
- Chamber ID: 12-5/16"
- Chamber internal height: 6-1/8"
- Converted the plasma source from a 1 MHz ICP to a 60 MHz CCP
- The target pedestal is symmetric about the center vertical axis and isolated from the grounded chamber with a 1" Teflon spacer.
- Tailored waveforms are produced by EHT RCC connected to the pedestal.



Argon plasma produced by a 60 MHz CCP with high voltage probe measuring the RF.

Impedans Semion Retarding Field Energy Analyzer (RFEA)

- G_0: reduces sampling orifice below the Debye length (floats relative to the pedestal voltage).
- G_1: large negative bias (relative to chamber ground) to repel plasma electrons (-60 + Bias)
- G_2: potential sweep (relative to chamber ground) to discriminate ion energies, (V_D range = (Range + margin) - Bias)
- C (collector) - small negative bias to collect ions but not accelerate them unduly to cause secondary electrons

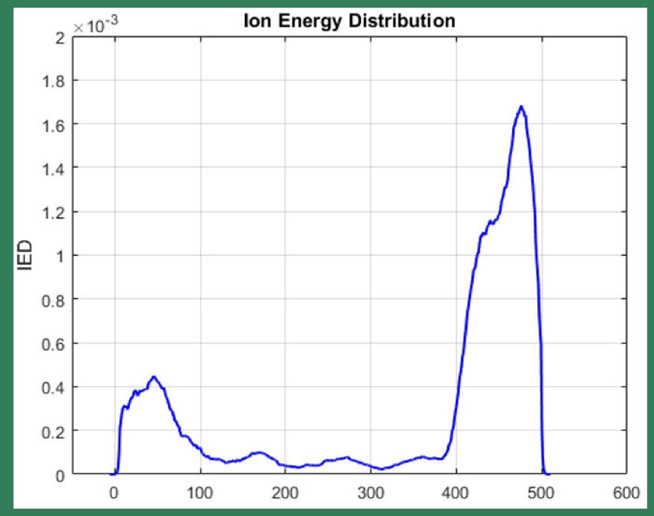


Top Left: Schematic of RFEA. Bottom Left: V_D at two different timescales showing delays, step sizes, and settling times. Right: Argon plasma potential measured with no bias waveforms at 300 W and 5 mTorr (ΔV_D = 1 eV). Each point averages ±5 points

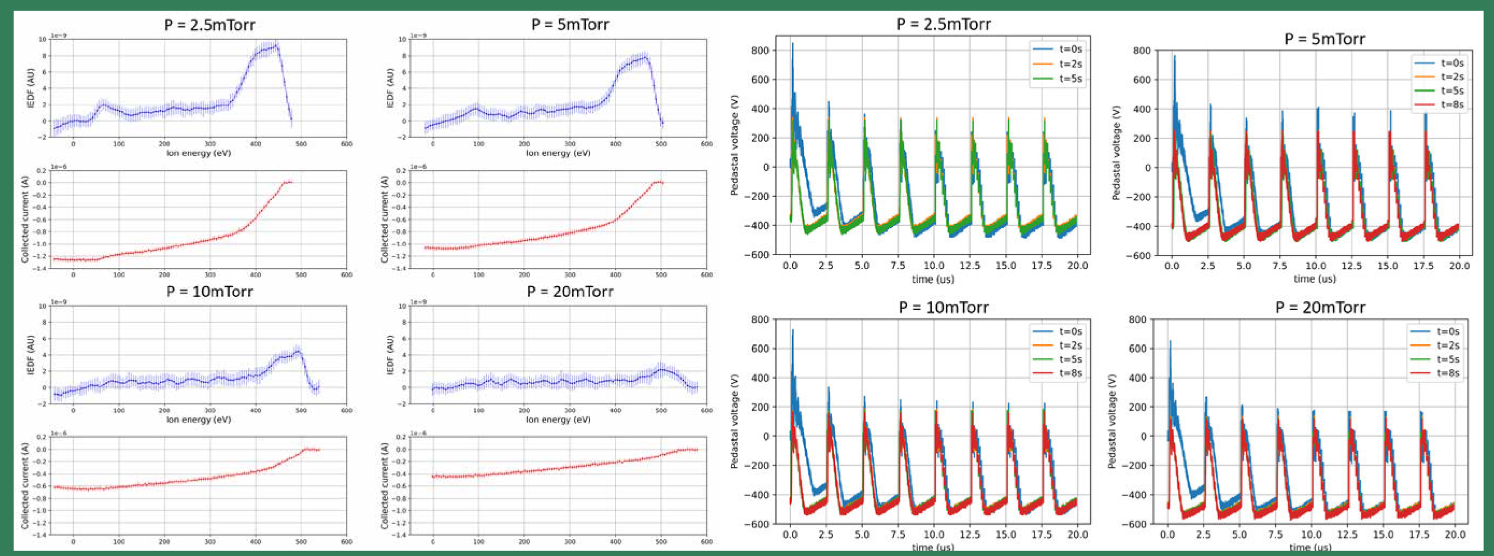
Calculated IED from Tailored Voltage Waveforms

The IED can be estimated from the measured bias waveform, plasma density, and temperature by applying Kirchhoff's Law to a circuit model of the sheaths.[1] The example is for PRF = 300 W, argon at 2.5 mTorr, and V_{charge} = 600 V. A boxcar smoothing function is applied.

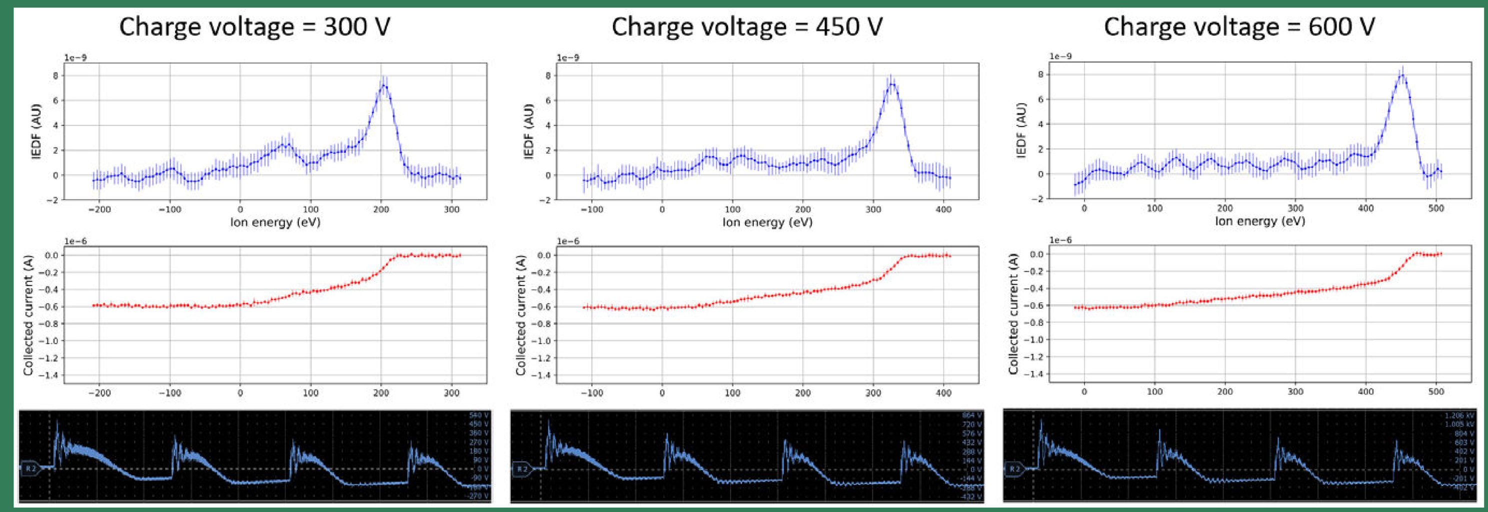
[1] P. Diomede, M. Nikolaou and D. J. Economou, "Voltage waveform to achieve a desired ion energy distribution on a substrate in contact with plasma" *Plasma Sources Sci. Technol.* 20 (2011) 045011



IED Measurements with Bias



Left: IED (blue) and RFEA ion current (red) at four different pressures with tailored voltage waveforms. Right: Tailored voltage waveforms (400 kHz & 600 V) applied to the pedestal at four different pressures. Waveforms at four different times were overlaid to show no significant changes to the tailored voltage waveform over the period that IED data was collected (IED and ion currents shown in plots to the left).



IED measurements for 100 W, 5 mTorr argon plasma with a tailored voltage waveform applied at three different charge voltages. The peak of the IED can be adjusted by changing the charge voltage of the RCC. Figure shows IED (top row), current collected by the RFEA (middle row), and voltage on the pedestal (bottom row).

Conclusion

- EHT upgraded the plasma source to a 60 MHz CCP and installed the Impedans Semion RFEA.
- EHT conducted a variety of experiments to baseline our understand of the diagnostic without tailored voltage waveforms.
- Measurements of the tailored voltage waveforms can be used to estimate the IED.
- The tailored voltage waveforms can be used to control the IED.

In the future, EHT will add additional diagnostics to the chamber and different plasma parameters will be explored. The RCC will be operated at higher voltages with different rise times different pulse repetition frequencies to improve our understanding of IED control. For more info: http://www.eagleharbortech.com/

Acknowledgment

This work was supported by a DOE SBIR (DE-SC0021716).