Improving Ion Control for Semiconductor Processing with Repetitive Pulsed Power Phase I

James Prager* (EHT), Timothy Ziemba (EHT), Amanda Lietz (Sandia)
*prager@eagleharbortech.com

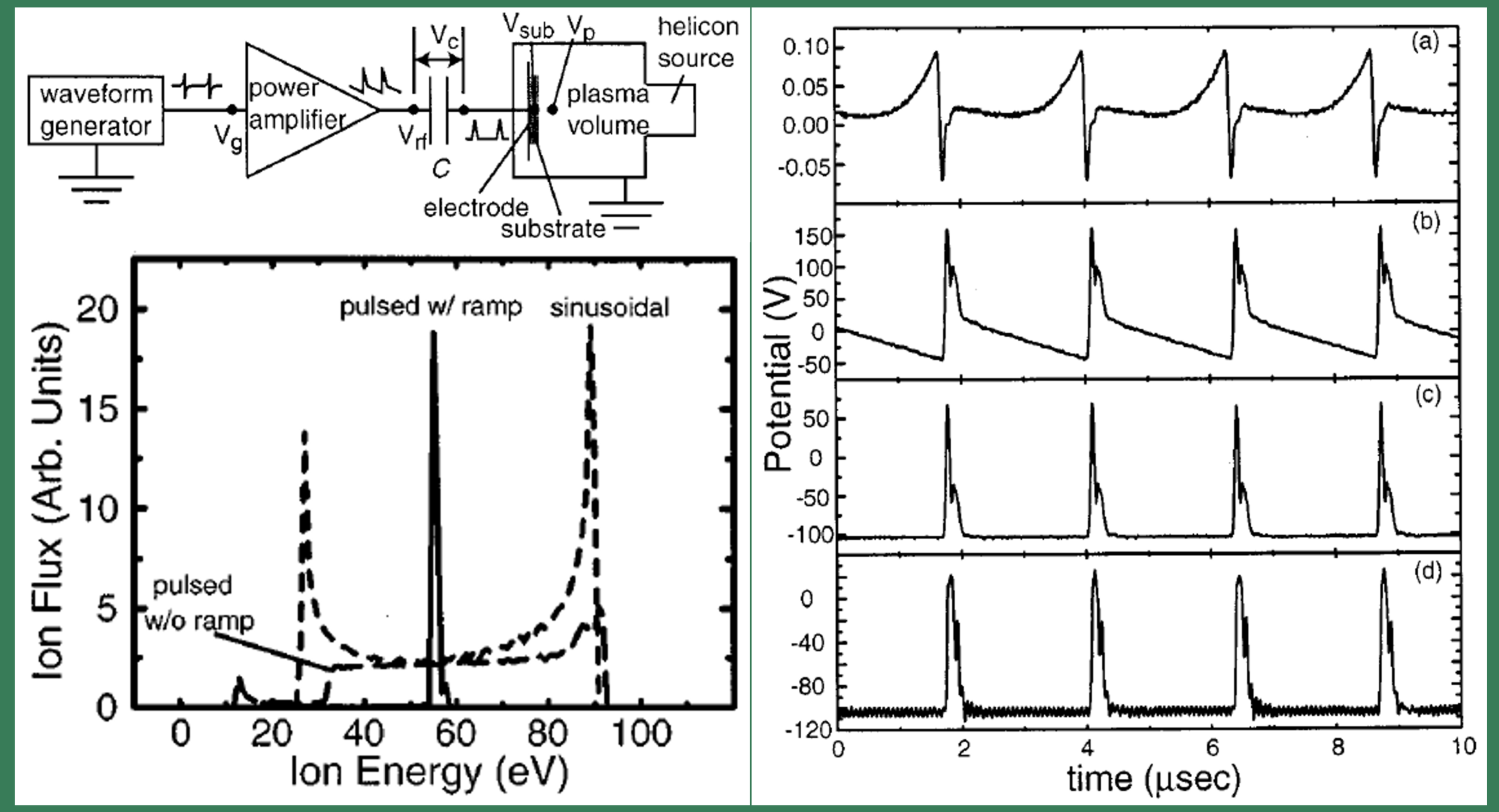
EAGLE HARBOR TECHNOLOGIES

Introduction

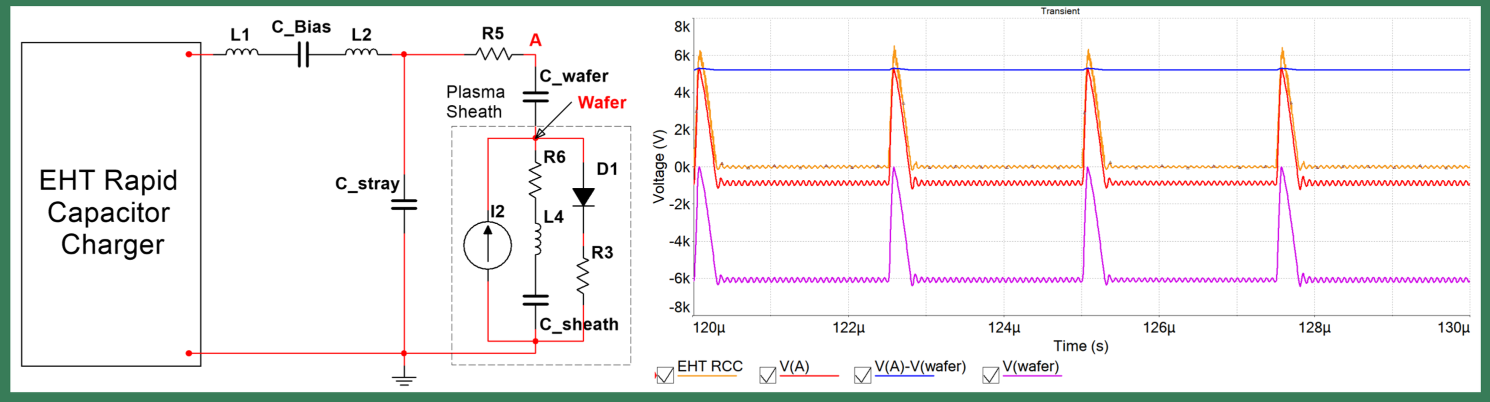
Using plasma etching to produce high-aspect-ratio (HAR) features is becoming increasingly important as the market demands solid-state non-volatile memory storage. To minimize bowing and twisting defects in HAR features, precision control of the ion energy distribution (IED) is required. Eagle Harbor Technologies (EHT), Inc. has previously developed a Rapid Capacitor Charger that can charge capacitance to high voltage in tens of nanoseconds and operate at 400 kHz. This power system can produce sheath voltage waveforms that are flatter than those produced with standard sinusoidal radio-frequency generators, which allows for improved control of the IED. EHT is experimentally verifying and optimizing the IED using these pulsed bias techniques. EHT built a retarding field energy analyzer to make precision measurements of the IED to demonstrate the efficacy of the new bias approach. Sandia National Laboratories is providing simulation support to help guide the experimental program.

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.

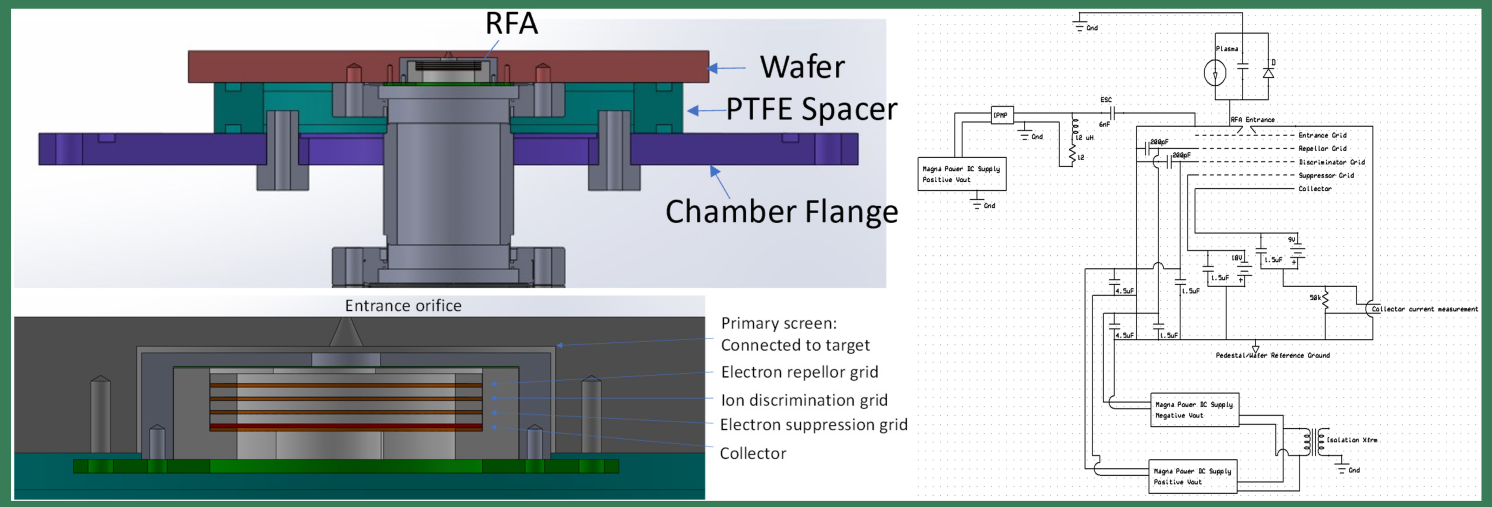


Left: Circuit diagram of EHT RCC with plasma load. Right: RCC SPICE modeling of wafer voltage: EHT RCC output voltage (orange), voltage at point A (red), voltage at the wafer (magenta), and the voltage across C_wafer ($V_A - V_{wafer}$ (blue)).

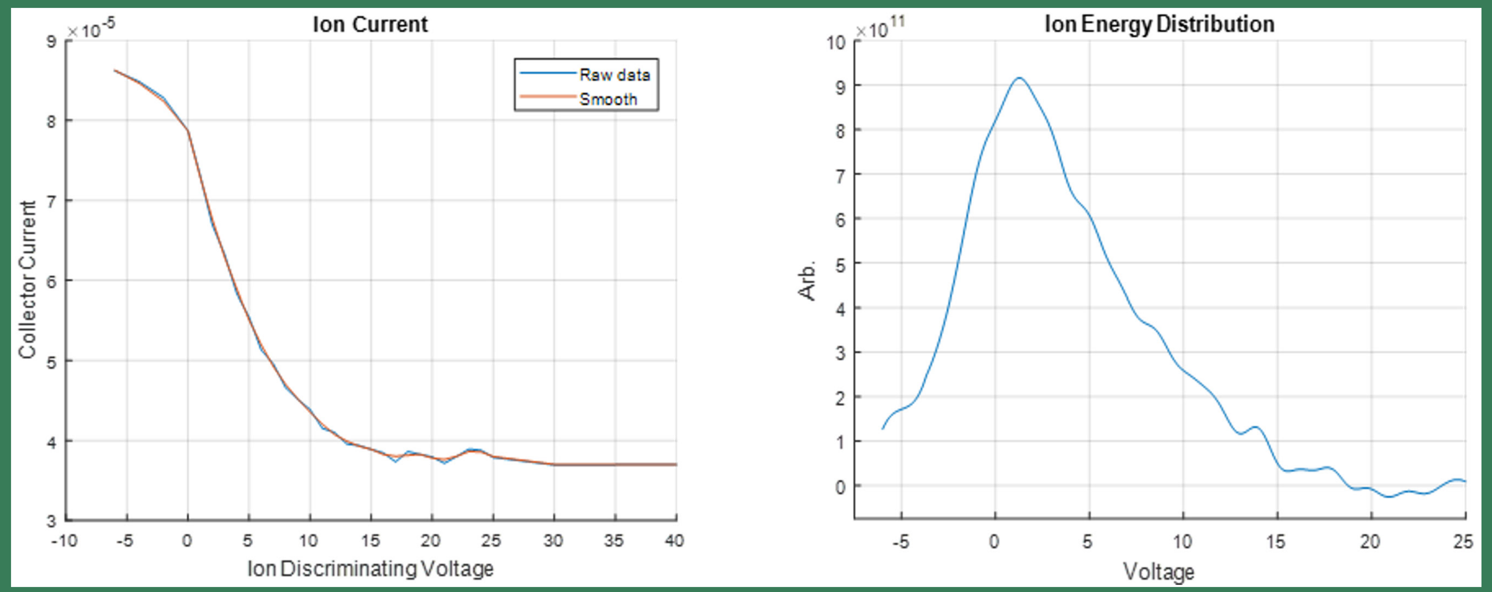
EHT Plasma Chamber

EHT tested the EHT RCC with plasma loads and made IED measurements. The chamber has an ID of 12-5/16" and the internal height is approximately 6-1/8". The target electrode/wafer, is symmetric about the center vertical axis and is isolated from the grounded chamber with a 1" Teflon spacer. In the initial work, EHT used an existing inductively coupled plasma source; however, in a potential Phase II, the chamber will be converted to a capacitively coupled plasma (CCP) source.

Retarding Field Analyzer and IED Measurements



Top Left: Cross-sectional view of the bottom of the process chamber showing the RFA location in the target electrode/wafer. Bottom Left: Close-up view of the RFA. Right: RFA wiring diagram.

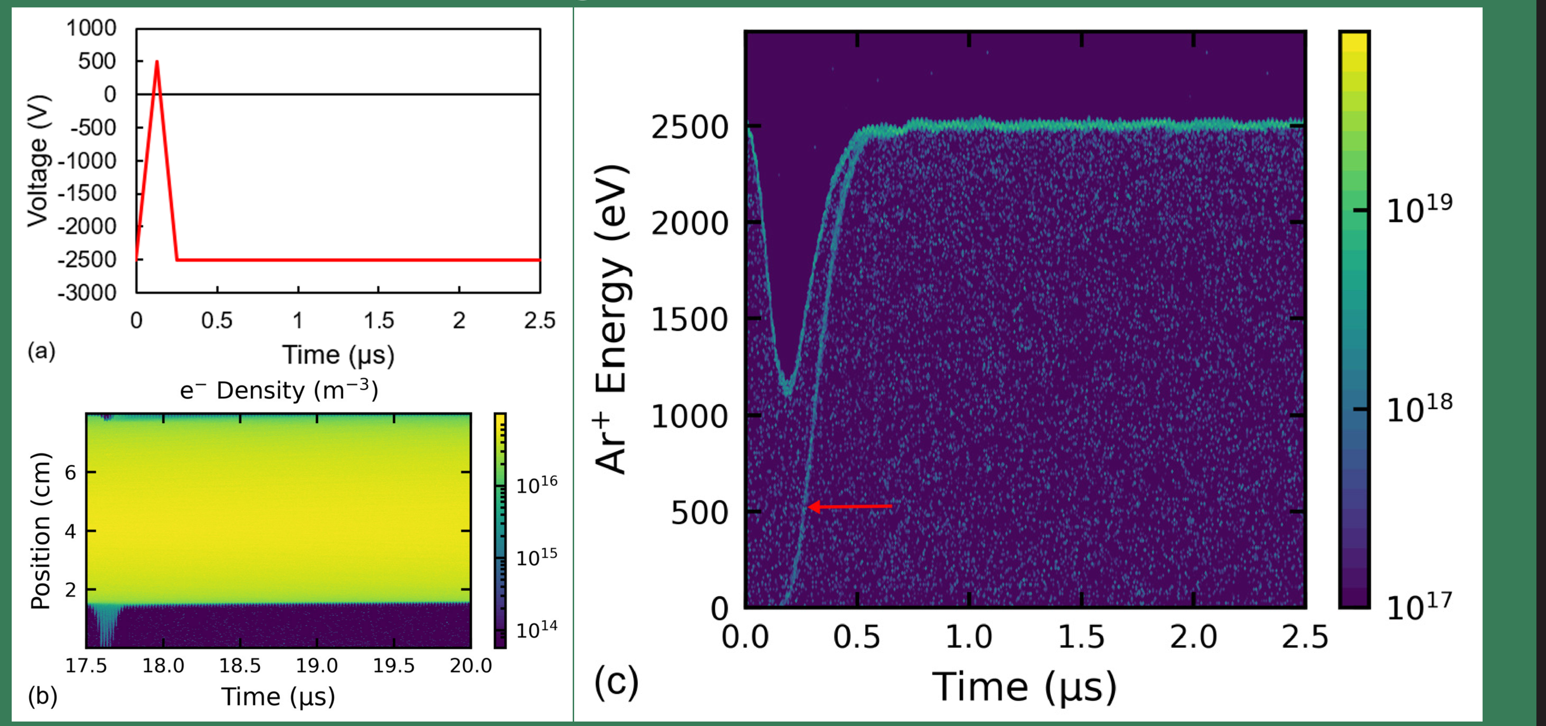


Left: I-V trace measured with the RFA. Right: The IED calculated from the I-V trace without bias voltage.

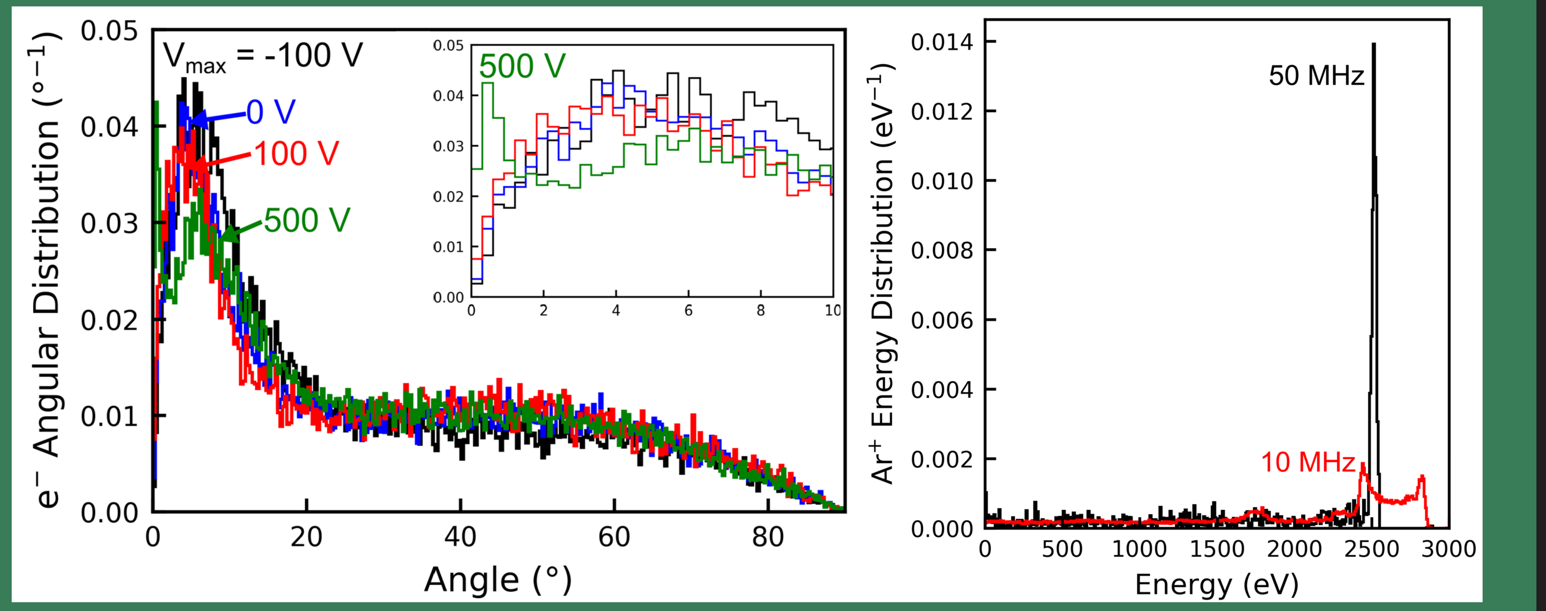
RCC Waveforms Measured with Plasma Load

RCC output voltage (yellow) and wafer voltage (blue) measured on the EHT process chamber for 20 mTorr operation.

Particle-in-Cell Modeling (Sandia)



1D CCP simulation in 5 mTorr Ar. (a) The custom voltage waveform applied to the lower electrode at 400 kHz. (b) Electron density across the gap over a single low-frequency cycle. (c) The time-resolved IED of Ar+ impinging on the lower electrode (i.e. the wafer) for a single low-frequency cycle.



Left: The electron angular distribution at the lower electrode for different DC offsets. Right: IED with bias waveform for a 600 V 50 MHz and 2 kV 10 MHz sources.

Conclusion

The EHT RCC has significant advantages over traditional RF power systems for wafer bias in industrial processing plasmas:

- Pulse shape can lead to precision control of IED, which allows the production of HAR features.
- The number of pulses during a burst can be precisely controlled.
- The voltage can be changed from pulse-to-pulse and burst-to-burst if necessary.

The combination of PIC modeling and experimental work can lead to significant improvements in ion control for semiconductor processing. For more info: http://www.eagleharbortech.com/

Acknowledgment

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