Retarding field analysis of the time averaged and time resolved ion energy distribution in RF and pulsed plasmas

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Talk outline

Introduction to Impedans Ltd.

- Retarding field energy analyser (RFEA) design and configuration
  - RF operation
  - Time resolved operation
- Ion energy distribution function measurements

  RF 13.56 MHz rf plasma

  ECR with 2MHz Bias

  Time Resolved Operation

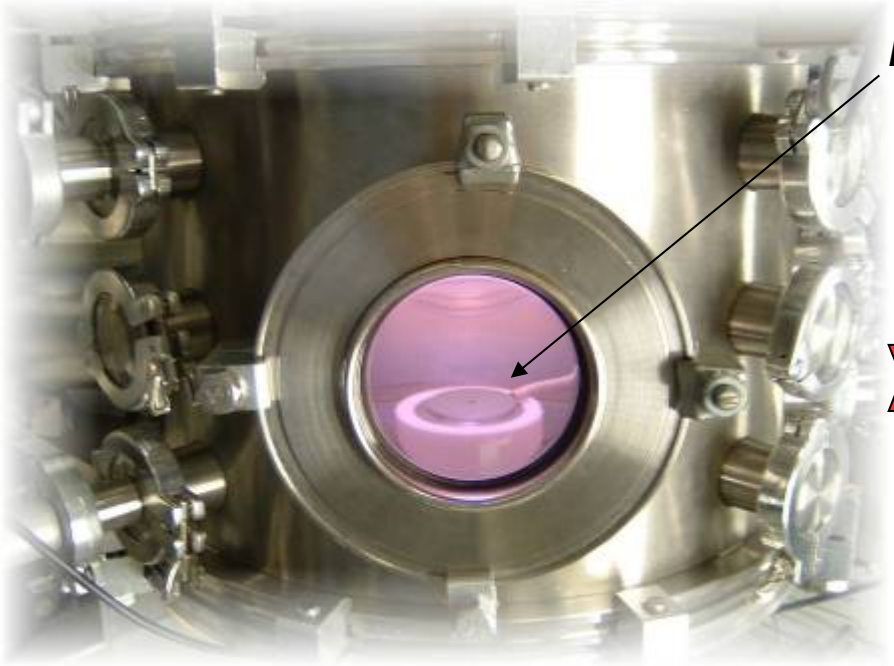
  HIPIMS Magnetron
- Conclusions

Our Vision

Our vision is to be the company of choice in leading-edge instruments and sensors for plasma characterisation, process monitoring and control.

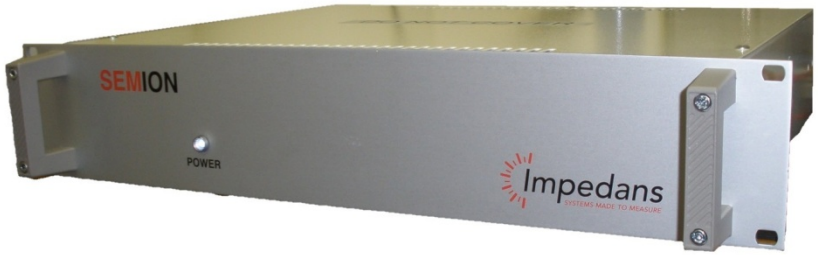
A Plasma Diagnostics "Single Source of Expertise"

Semion RFEA Technology



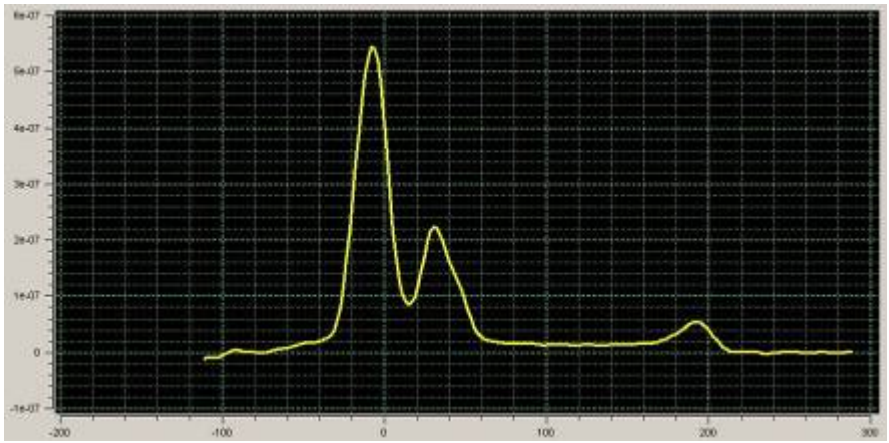
RFEA PROBE

SEMION™ SYSTEM



PLASMA PROCESS

The Semion System is a plasma diagnostic instrument which measures the ion energy and ion flux present at the substrate surface under grounded, self-bias, RF bias and Pulsed DC/RF bias conditions.



Ion Energy Distribution

Semion™ RFEA Probe Variants

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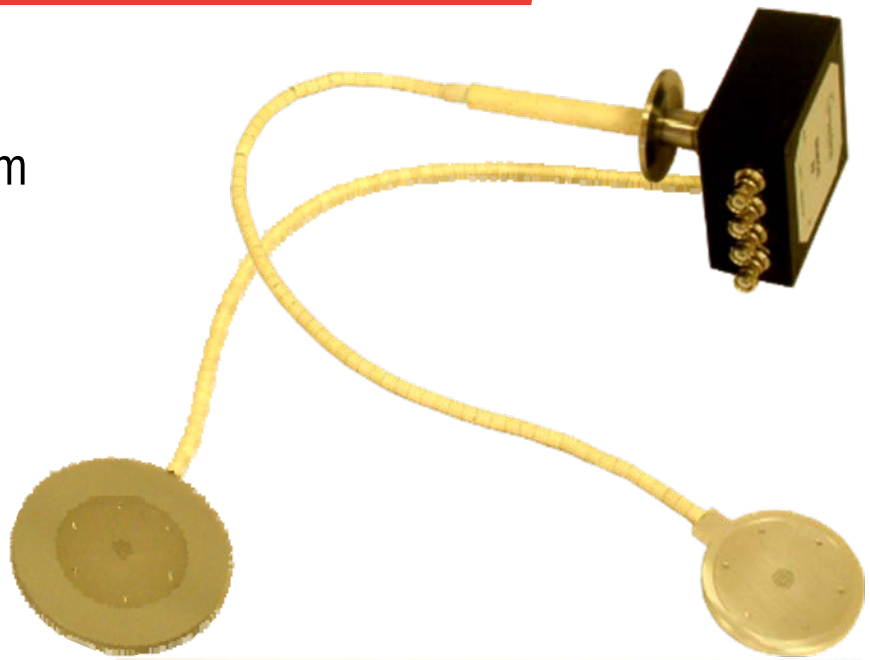
Standard 70mm and 100mm (4”)Aluminium RFEA Probe and holder

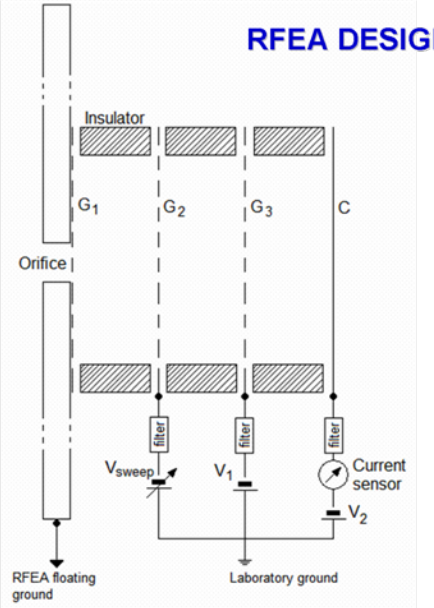
- Standard plasmas Ar, O_2 etc.
- Deposition Plasmas CH_4, Ti etc.



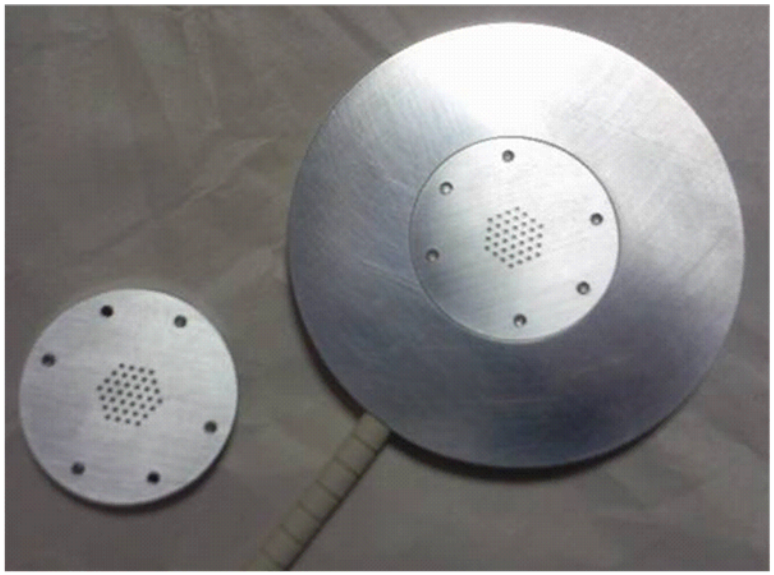
100mm (4”) & 300mm (12”) Anodized Aluminium RFEA Probe and holder

- Etch plasmas
- Compatible with various etch chemistries

RFEA Design



- G1, prevents plasma entering RFEA.
- G2, bias sweep to discriminate charged species energy.
- G3, biased negatively to repel plasma electrons. Also prevents secondary electrons escaping from C.
- C, collects charged species for detection.
- Filters allow RFEA to sit on biased substrate.
- Novel filter design allows 100ns time resolution through the filter



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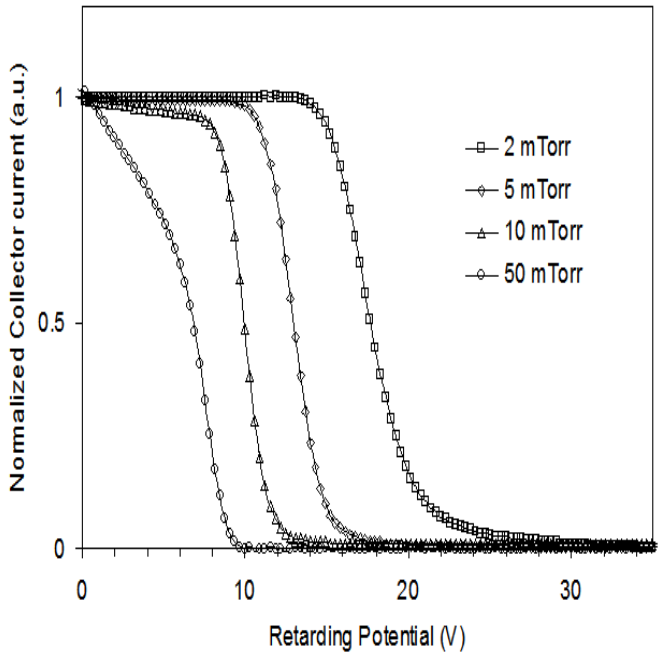
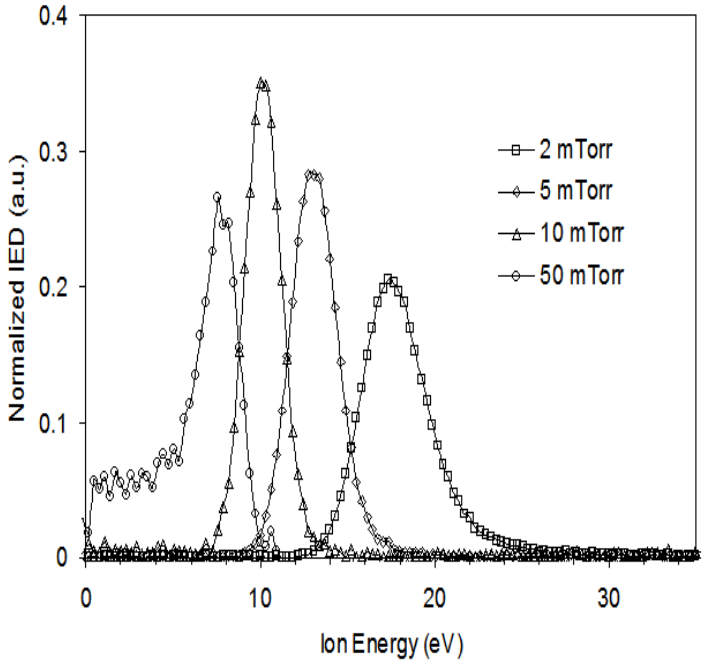
Current Voltage characteristic and IEDF

RESULTS



Current-voltage characteristics at various discharge pressures for the grounded electrode.



Ion energy distributions calculated from the current-voltage characteristics.

CCP Plasma reactor Case 1

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Oxford instruments CCP

- Single frequency 13.56MHz
- 200mm chuck
- Argon Gas
- 10 – 20 mTorr
- 10 – 100W
- Unconfined plasma – geometrically asymmetric discharge
- RFEA embedded in a 200mm holder and sits on the chuck
- Langmuir probe located in mid-plane of discharge

IEDF Measurement - Semion

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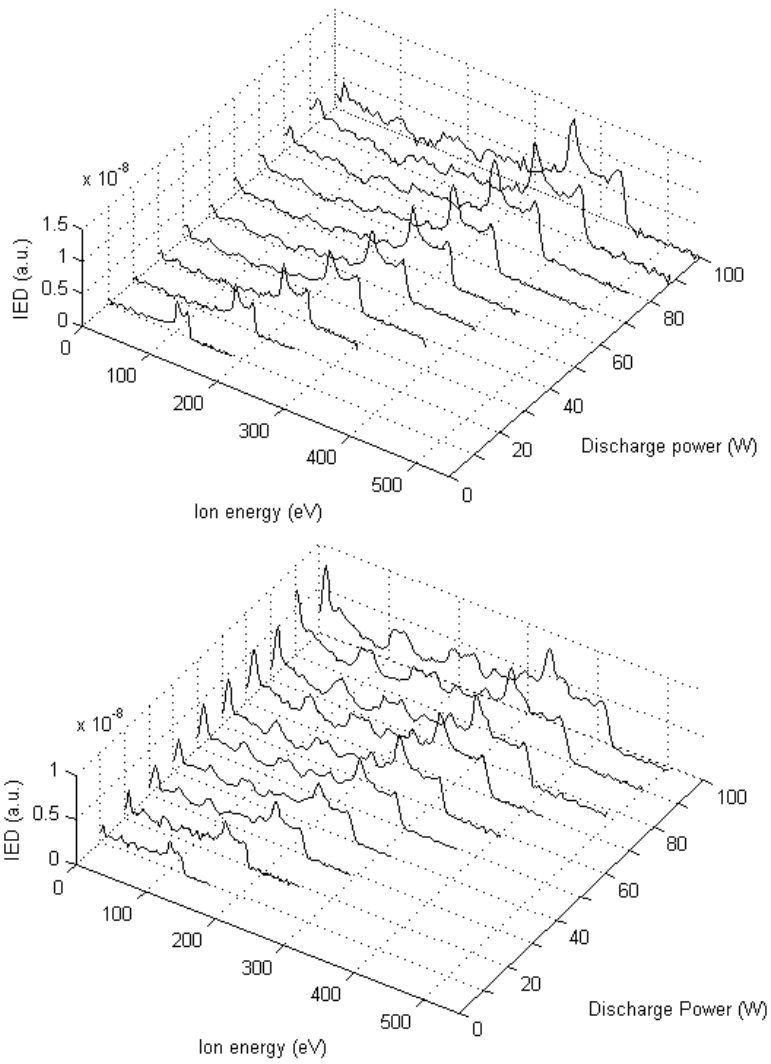
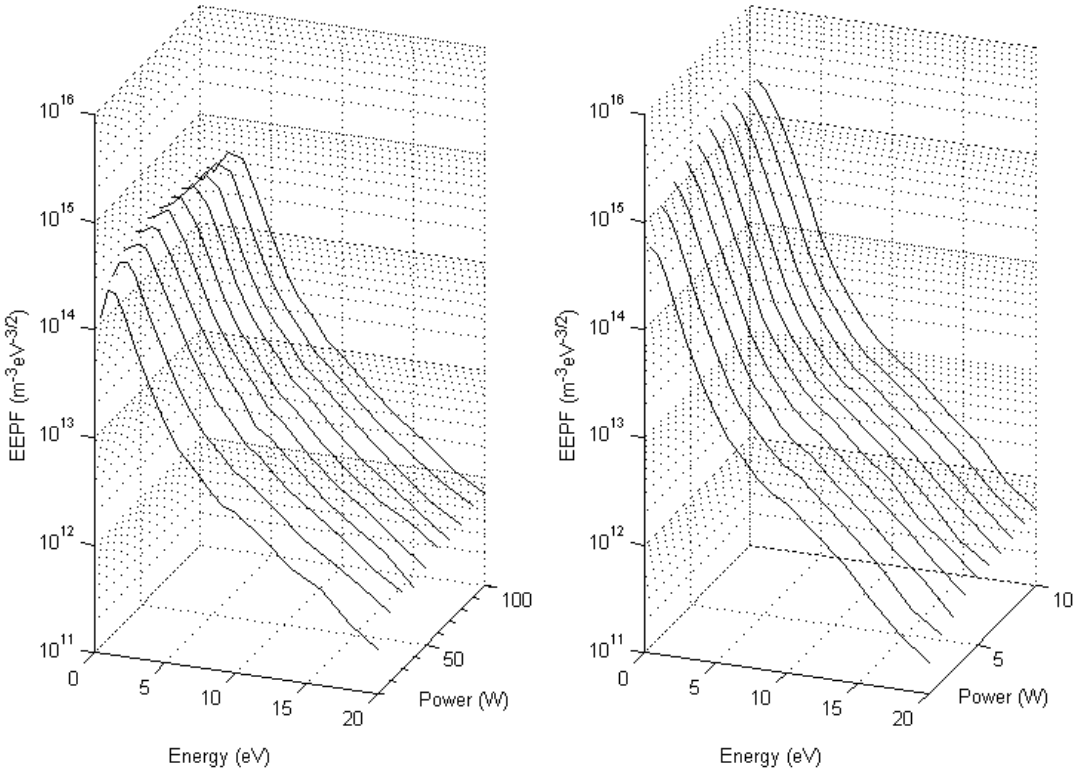
Ion energy distributions measured at the powered electrode at pressures of 10mTorr (top) and 20mTorr (bottom).



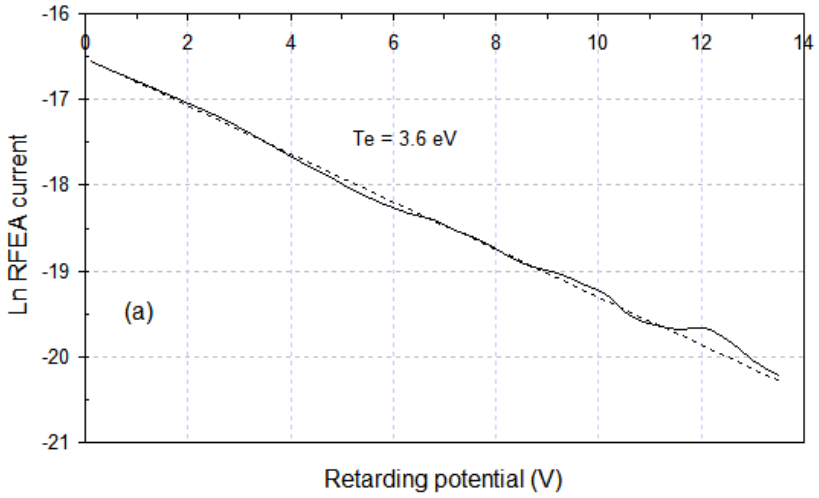
EEDF Measurement – ALP System

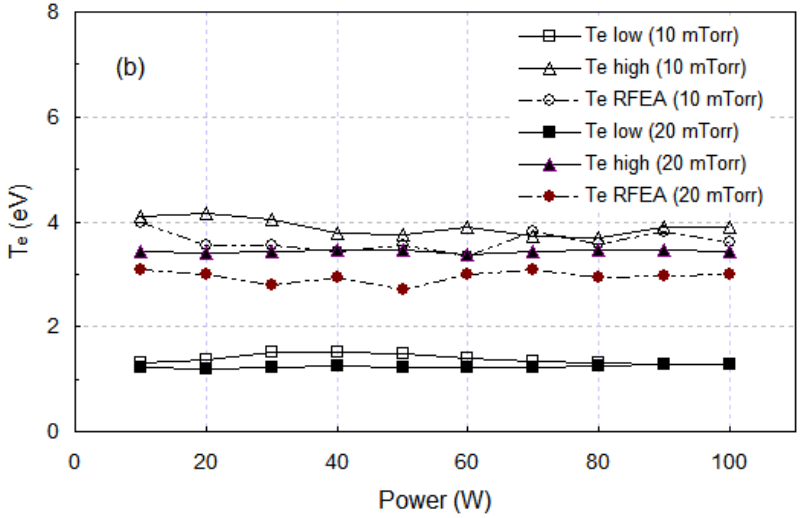
Langmuir probe measurement of the EEDF in the discharge centre at 10mTorr (left) and 20mTorr (right).



EEDF Measurement – Semion

- EEDF measurement at powered electrode (top).
- The electron temperature measured with Semion at the electrode are compared with the electron temperature measured in the bulk plasma with the ALP System.
- Te low and Te high refer to the temperature of the low and high energy electron populations in the bi-Maxwellian EEDF.
- Te determined with Semion agree well with the Te high values determined with the ALP System. Only the high energy population can reach the electrode for detection.





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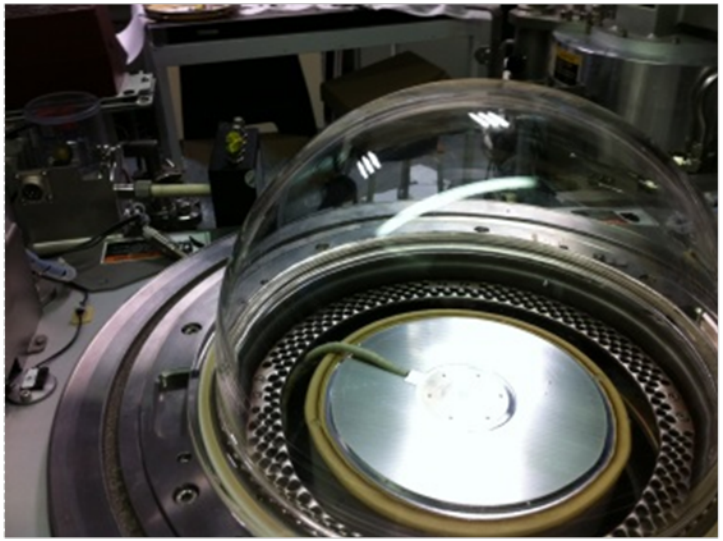
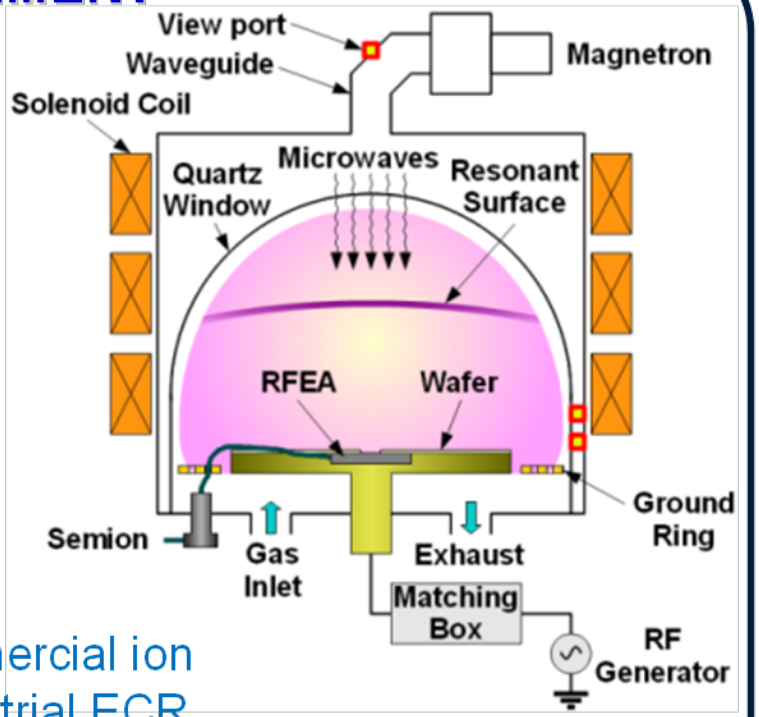
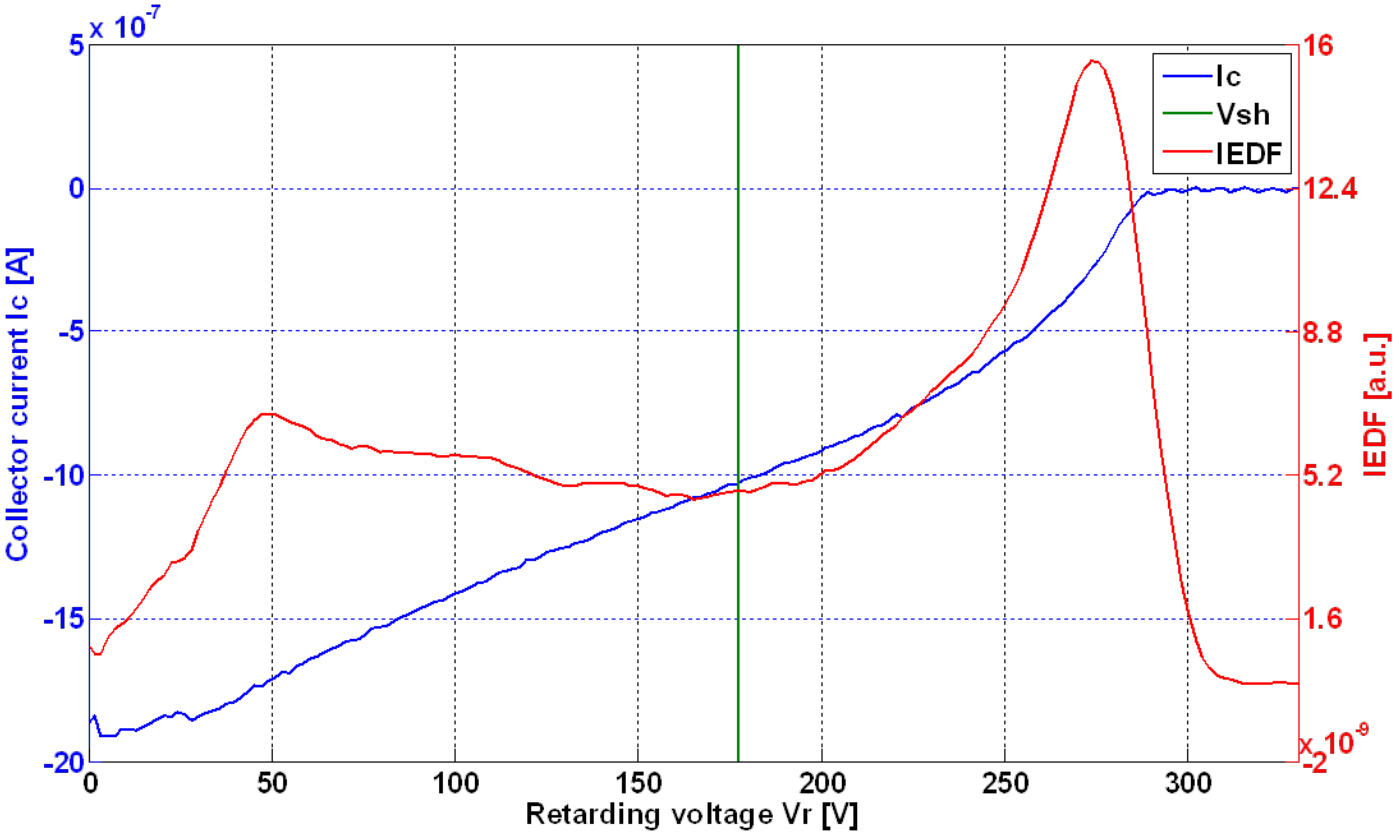
EXPERIMENT



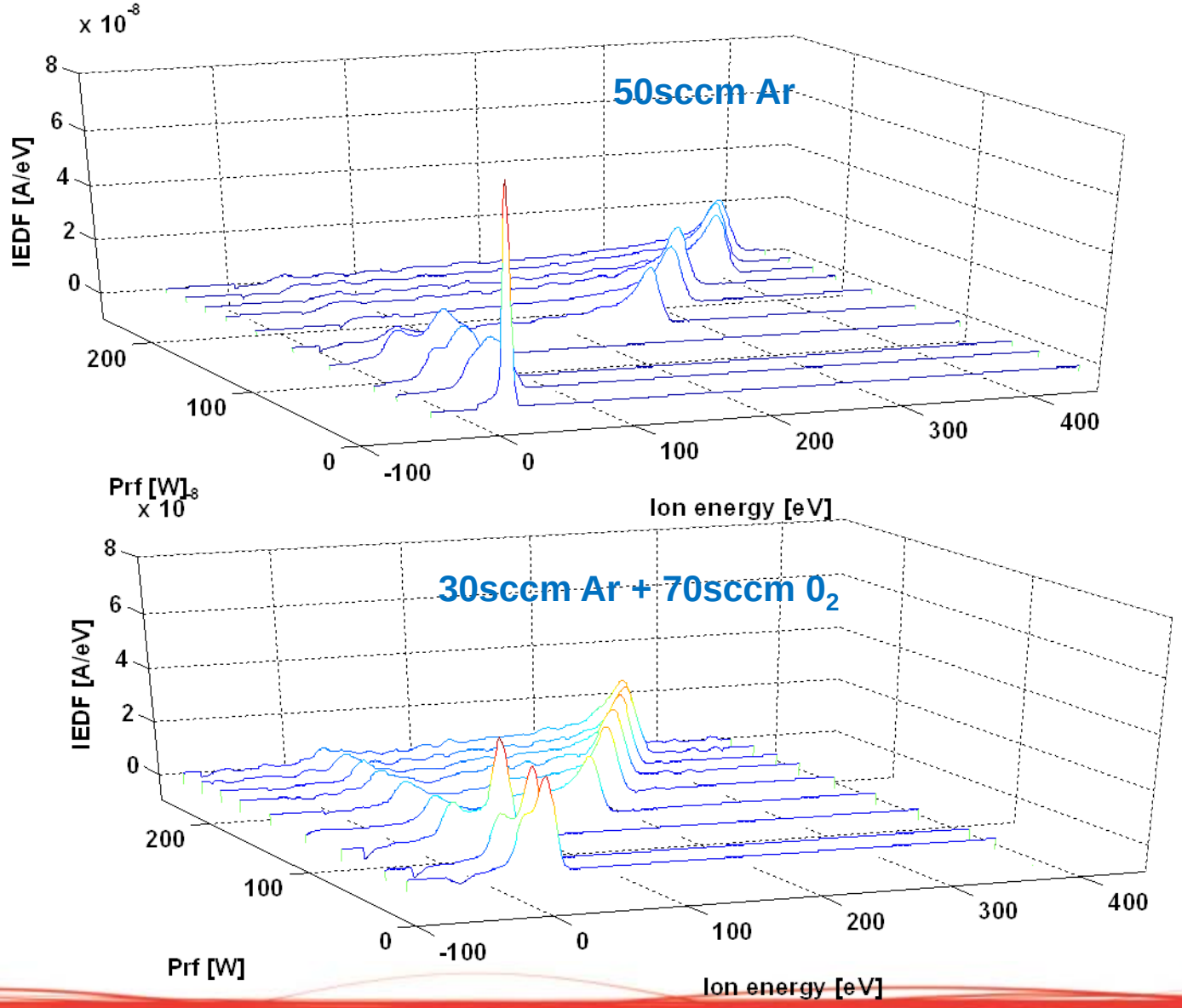


Experimental set up showing commercial ion flux probe (RFEA) installed in industrial ECR etching reactor. RFEA is mounted in sensor holder sitting on RF bias electrode. Wafer sitting on top of sensor holder has drilled hole in the middle to allow plasma reaching RFEA orifice. Cabling from RFEA sensor has been taken out through an existing unused port located in vacuum pump tunnel.

Typical IEDF Ion Energy Distribution Function



Effect of Gas composition and Anomalous energy shift



Comparison of two measured IEDF profiles obtained from plasmas with different gas chemistries. Both measurements used SiO2 wafer sitting on top of RFEA.

Statistical Model Ion Energy and Flux not decoupled

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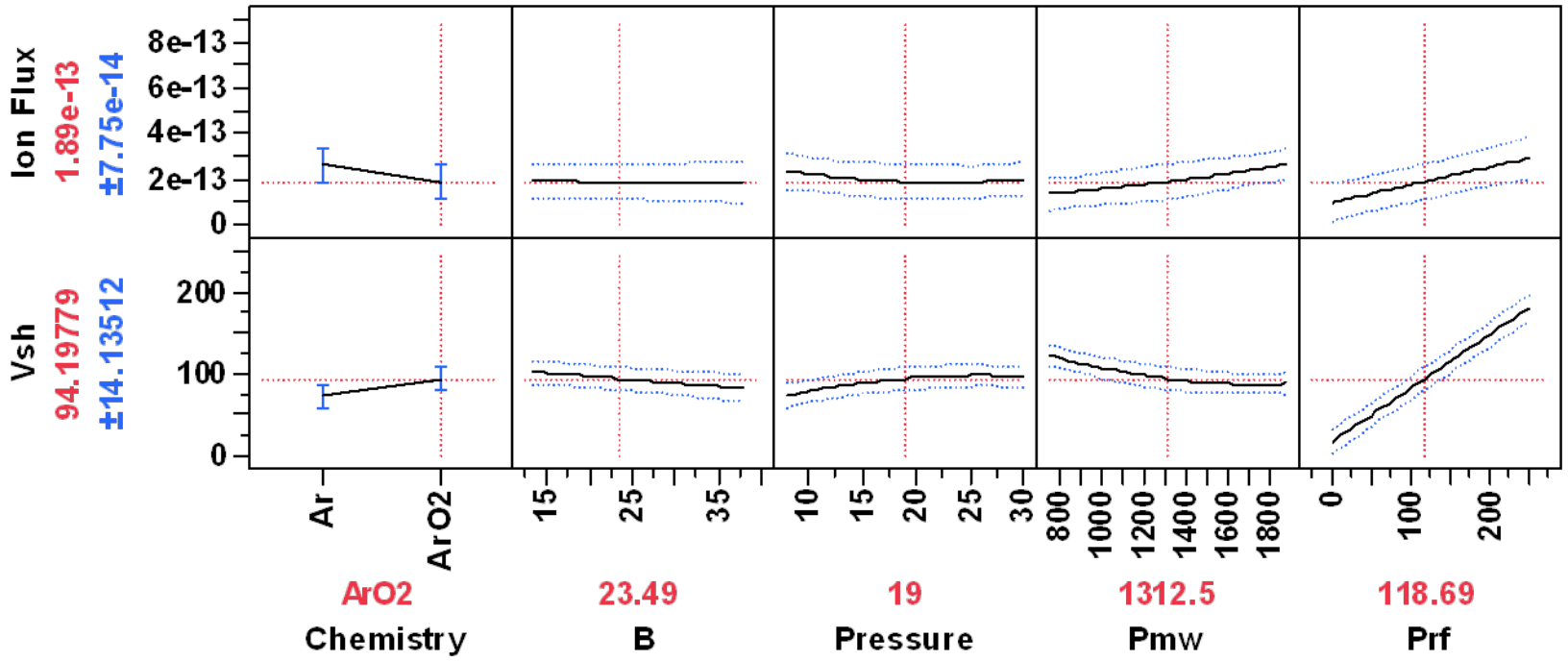
Ion Flux depends on Prf the Bias Power

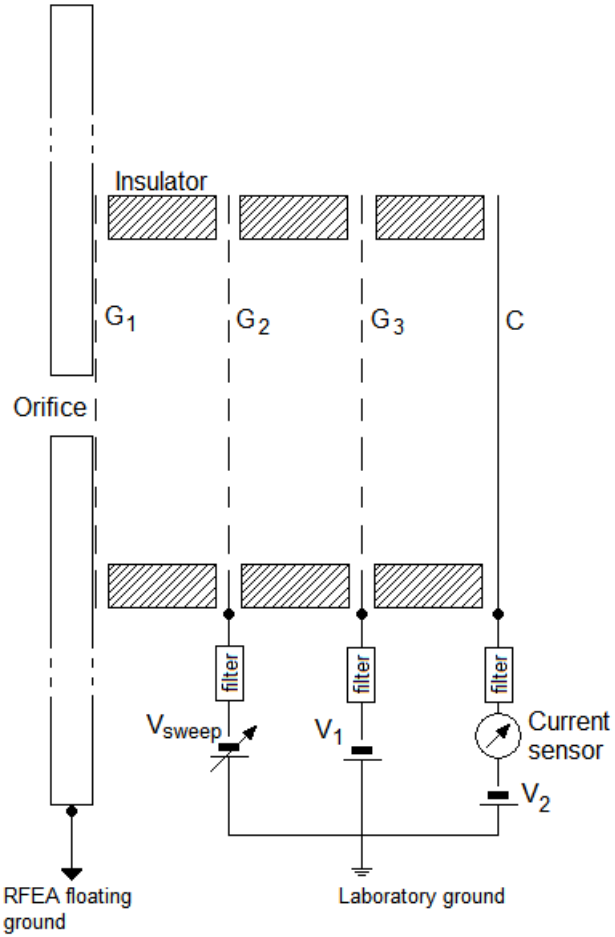


RFEA Design For RF applications

Retarding Field Energy Analyser

Standard configuration for time averaged operation

- G_1, prevents plasma entering RFEA
- G_2, potential sweep, ion discrimination
- G_3, negative potential, electron repulsion
- C, negative potential, ion attraction
- RF filters allow Grids and C float at RF bias
- Input Impedance > $10^5\,\Omega$, 500kHz – 100MHz
- Attenuation > 60dB
- Cable takes RFEA signals to feedthrough mounted at reactor wall



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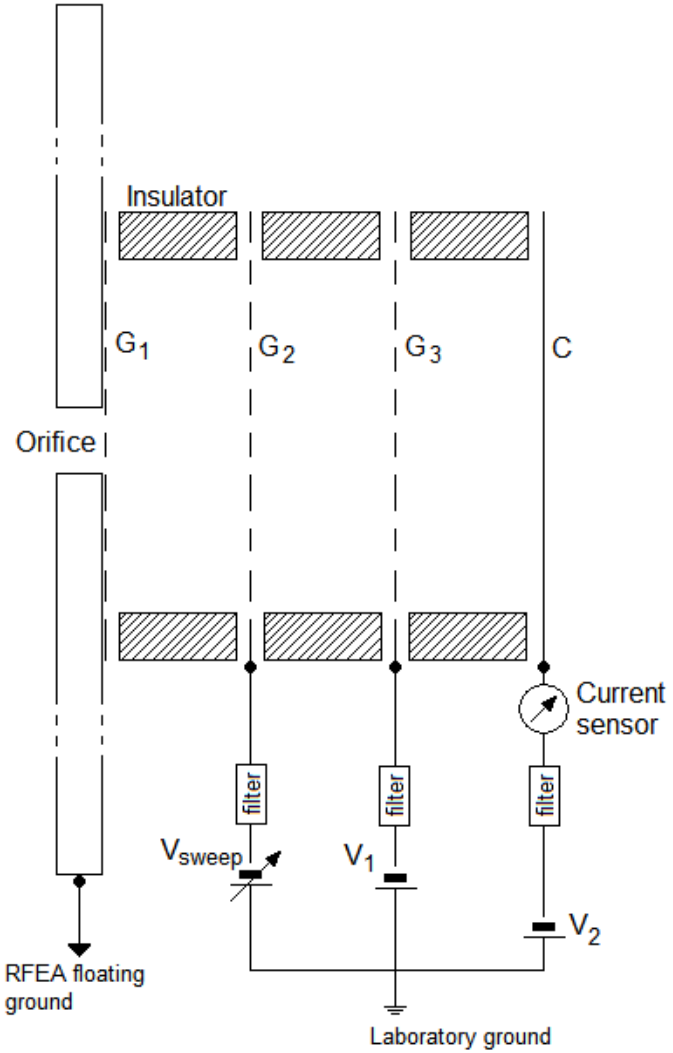
pDC RFEA Design

Time resolved IEDF measurement

- Signal measured before filtering
- Synchronised with bias waveform
- Time resolution ~ 100 ns
- Driven by needs of Pulsed plasma community ~ 350kHz pDC
- Operating frequency range 1kHz - 2MHz @ ~ 400V pk-to-pk bias.
- No frequency or bias limits if mounted on a grounded surface



Pulsed Bias CCP Plasma reactor

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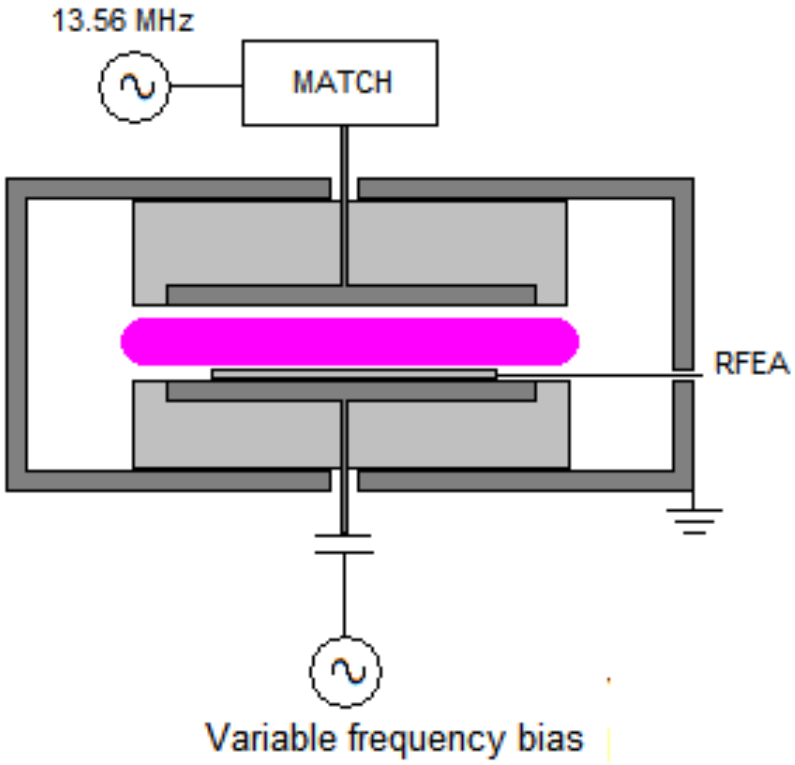
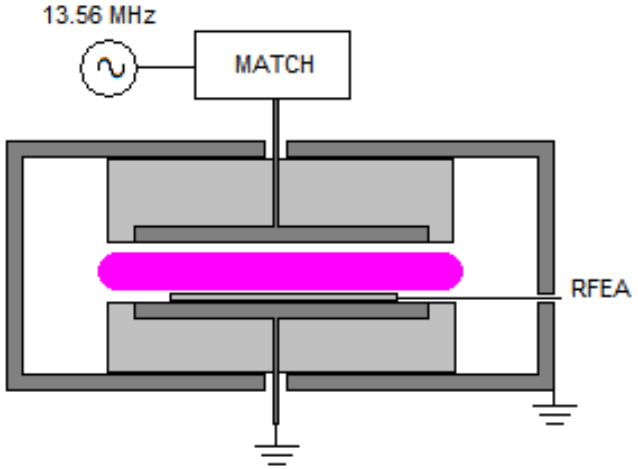
Plasma reactor and experimental conditions

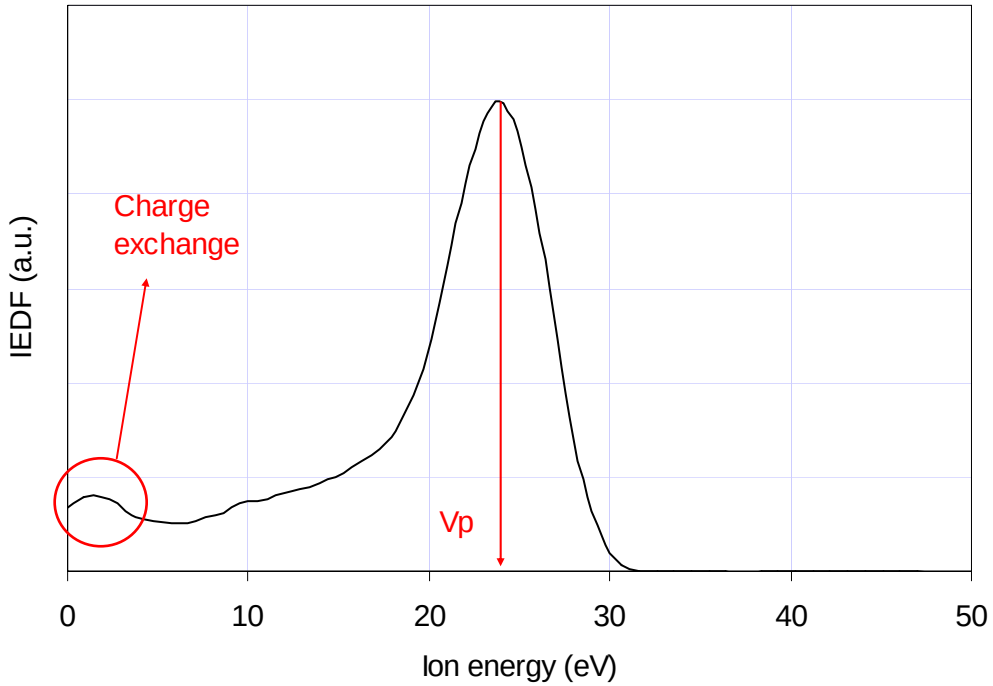
- Custom CCP design
- Electrode diameter 140 mm (S/S)
- Gap ~ 40 mm
- Usually CW 13.56MHz applied to top
- 13.56 MHz source can be pulsed to 1kHz
- Bottom electrode usually grounded
- Variable frequency bias can also be applied through blocking capacitor, not matched
- RFEA sits on lower electrode



Continuous RF IEDF

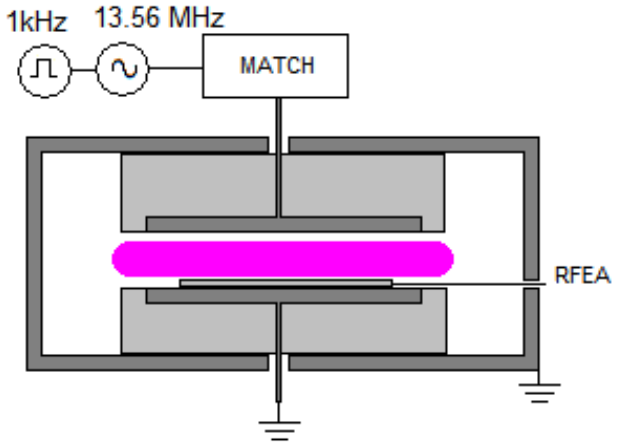
- Bottom electrode grounded
- 30 W Source power
- 2.5 Pa, Argon gas
- Time averaged IEDF

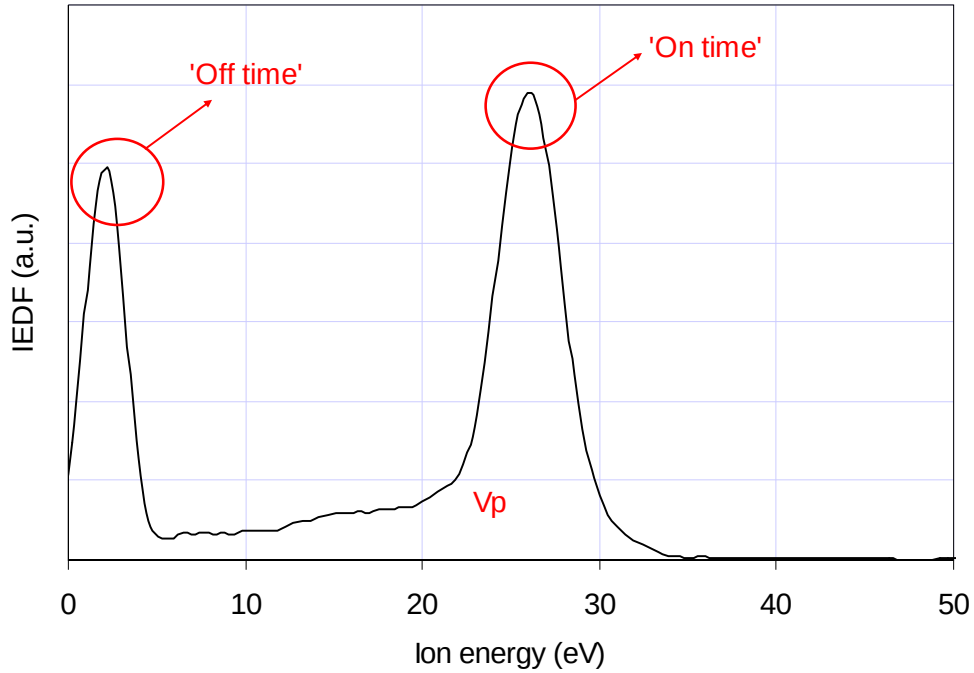




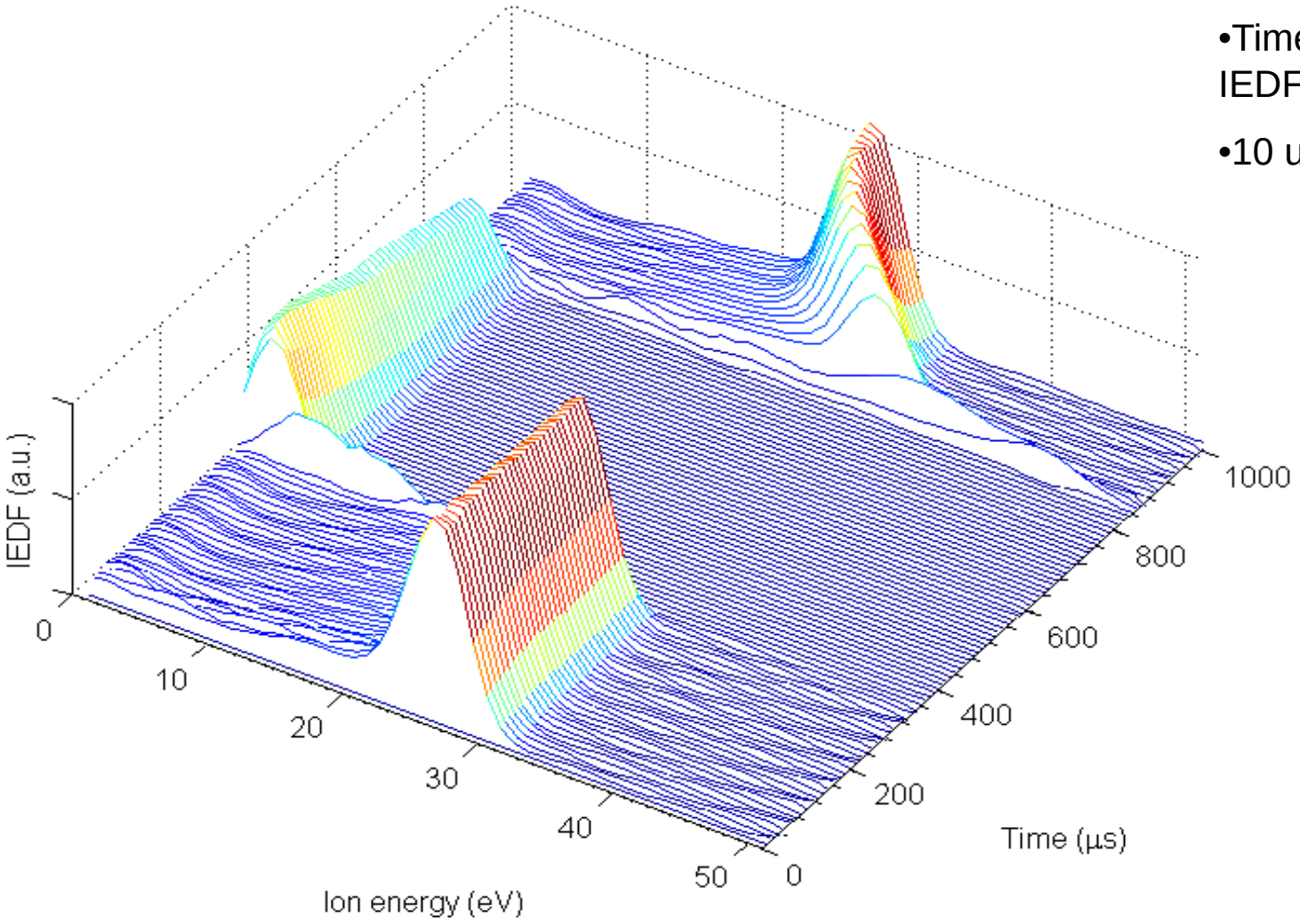
Time Averaged Pulsed RF Plasma

- Bottom electrode grounded
- Source modulated at 1 kHz
- Square wave modulation, 50% duty, 100% modulation depth
- Significant ion flux during ‘off’ time
- Time averaged IEDF



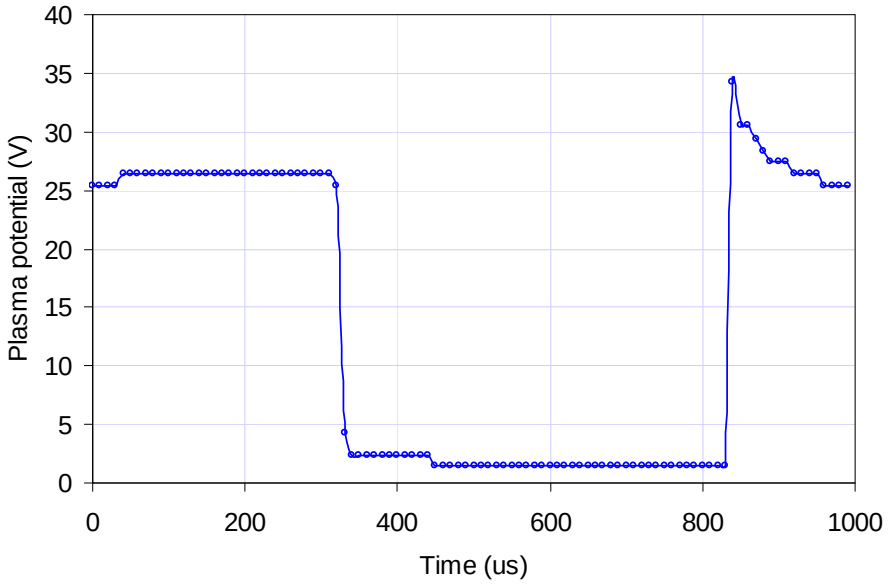


Time Resolved IEDF

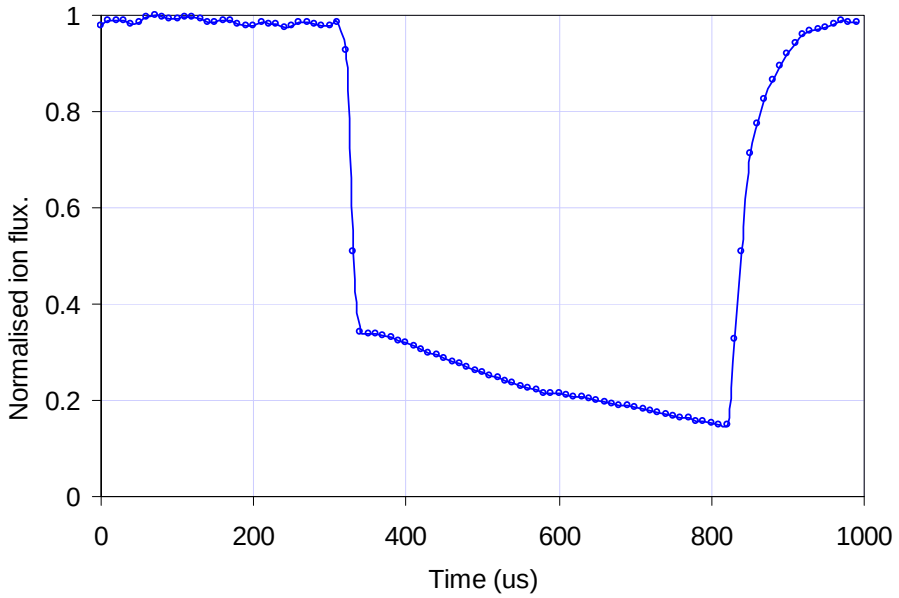


- Time resolved IEDF
- 10 us resolution

Time Resolved Vp and Ion Flux

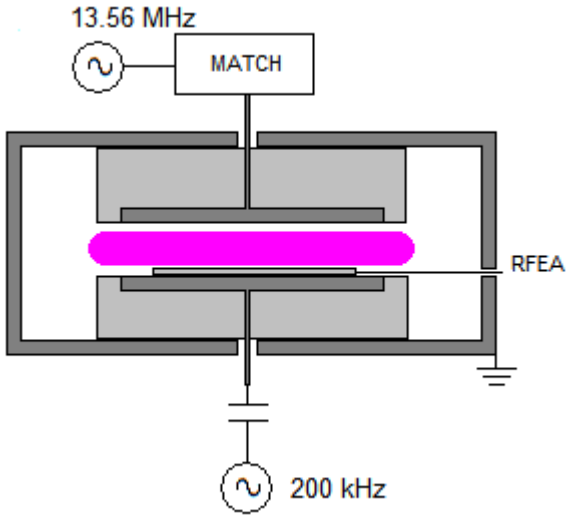


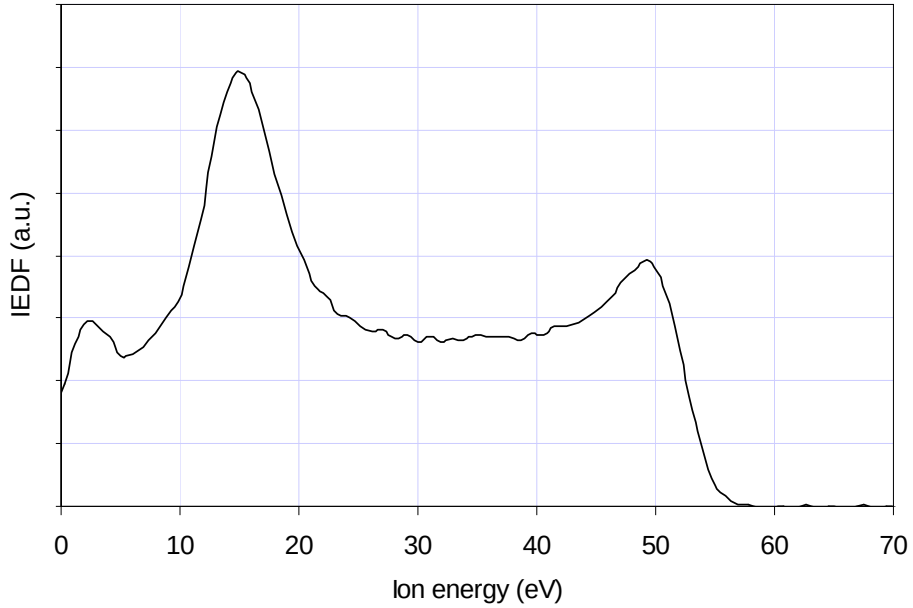
- Plasma potential and normalized ion flux through pulse period
- Plasma potential approximately equivalent to the peak ion energy
- Ion flux equal proportional to the integral of the IEDF

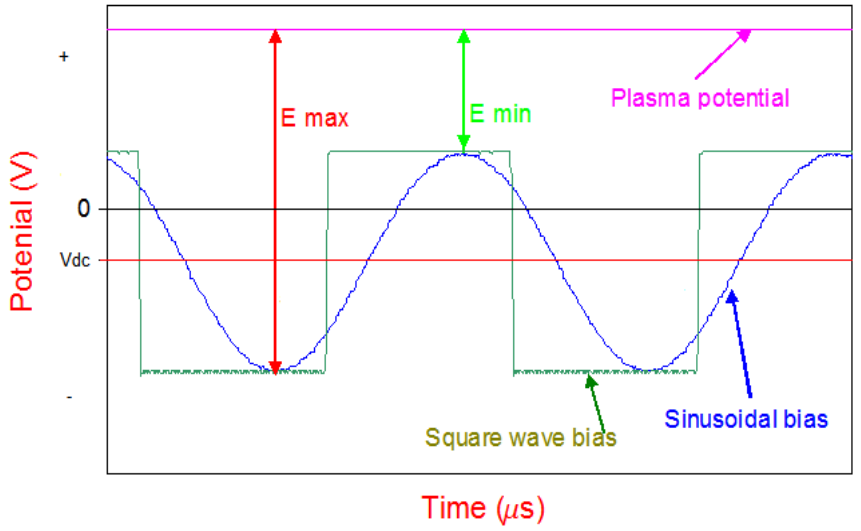


Time Averaged 200kHz Bias

- Sinusoidal 200kHz bias
- Standard saddle shaped structure
- Time averaged IEDF

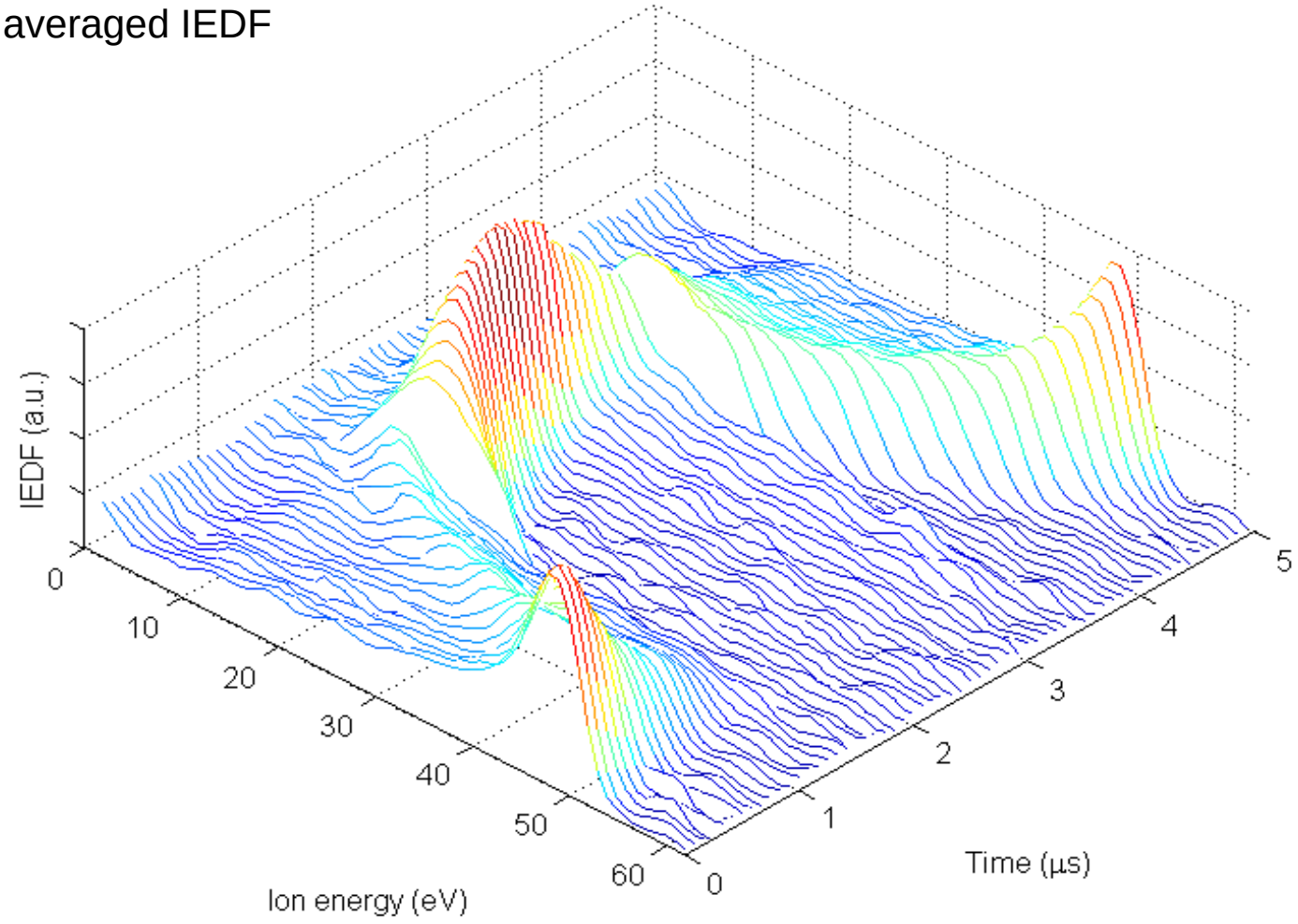






Time Resolved 200kHz Bias

- Snapshots at 100ns intervals
- Time averaged IEDF



Ion Flux Modulation at 200kHz

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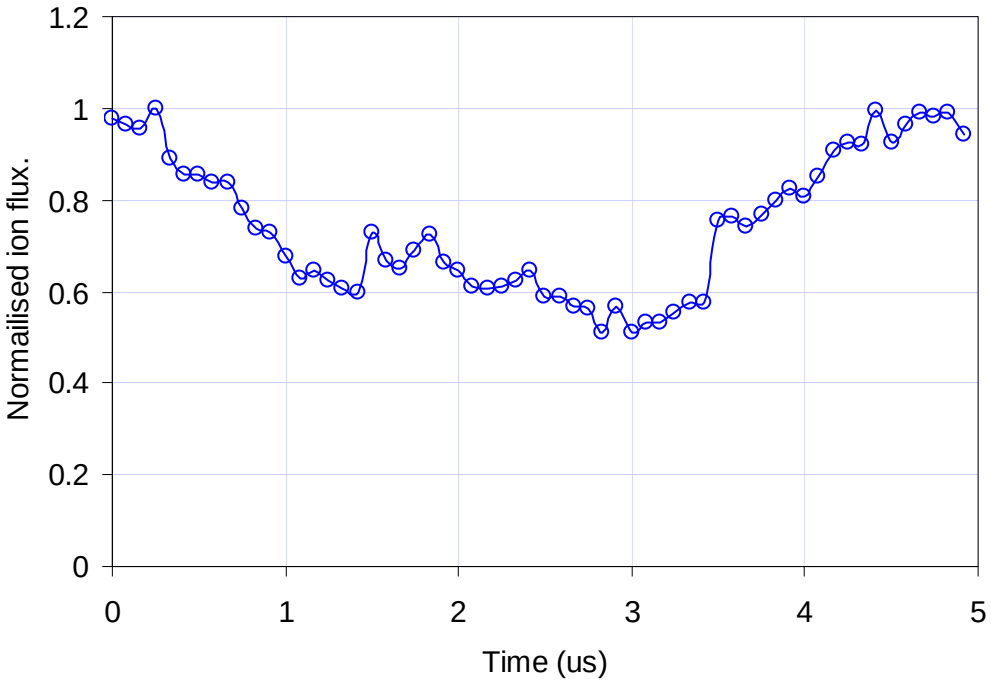
•Ion flux modulated at bias frequency



Time resolved ion energy distribution measurement at the substrate in a magnetron sputtering reactor.

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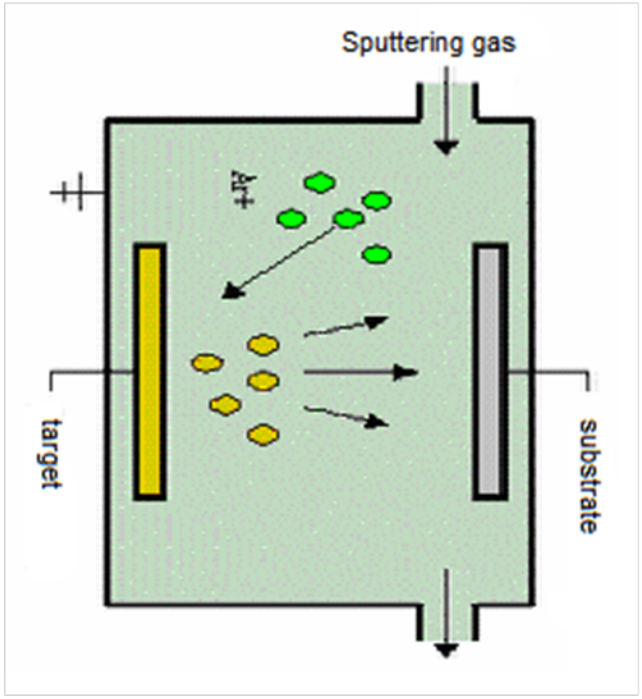
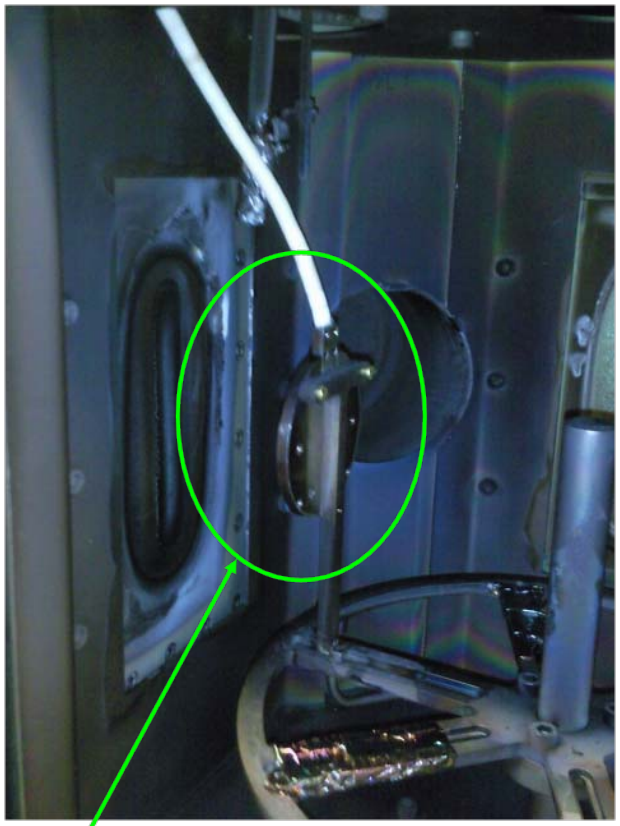
EXPERIMENTAL



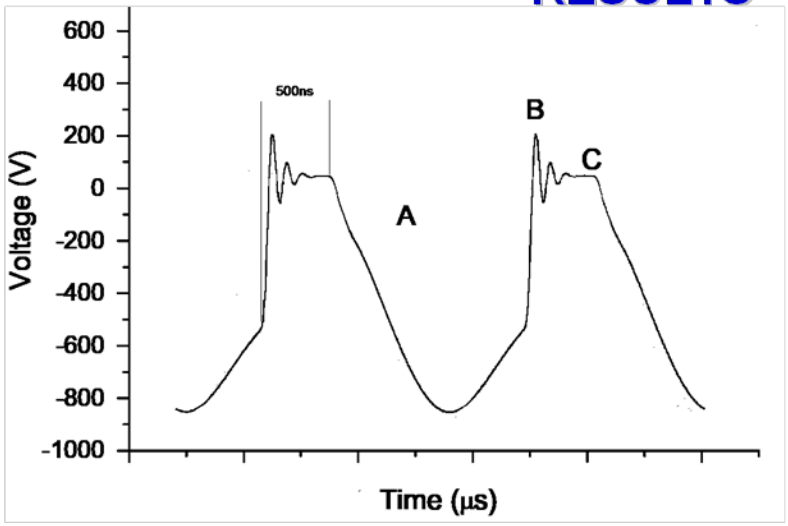
- 350 kHz pulsed DC bias applied to the target
- Titanium target used in this experiment
- Substrate was electrically floating
- Sputtering gas used was argon

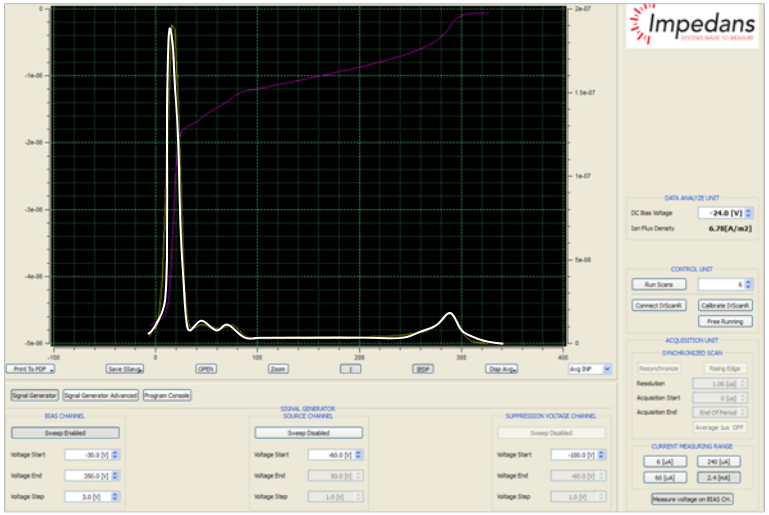


RFEA facing titanium target

Average IEDF

RESULTS

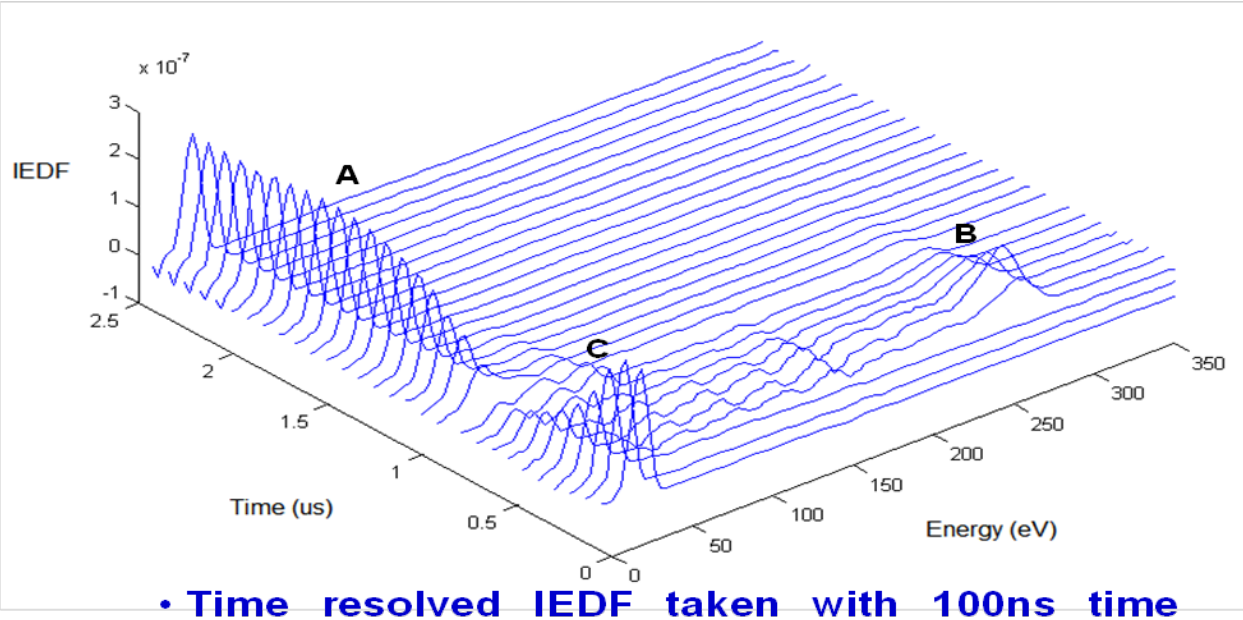




- Bias waveform, 500ns off time
- A = on time, B = ringing, C = off time
- A, B and C induce different ion energy

- Semion software showing the time averaged IEDF. This shows multiple ion energy peaks but does not indicate during which phase of the bias period these peaks were generated.

Time Resolved IEDF
Showing origin of anomalous energy high ions



- **Time resolved IEDF taken with 100ns time resolution through the pulse period.**
- **Clear indication of when each energy peak is created**

Conclusions

• RFEA is a robust tool to measure Ion Energy Distributions in RF plasma even on a biased substrate.

•RFEA design suitable for time resolved measurement of IEDF in pulsed plasmas presented.

• Resolution of 100ns and ability to function on biased surface demonstrated.

• IEDF has considerable structure during the bias period.

• Ion flux appears to be modulated by the bias waveform.

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Thank you for your attention!