Evolution of RFEA Measurements at the Substrate

Impedans
Plasma Measurement

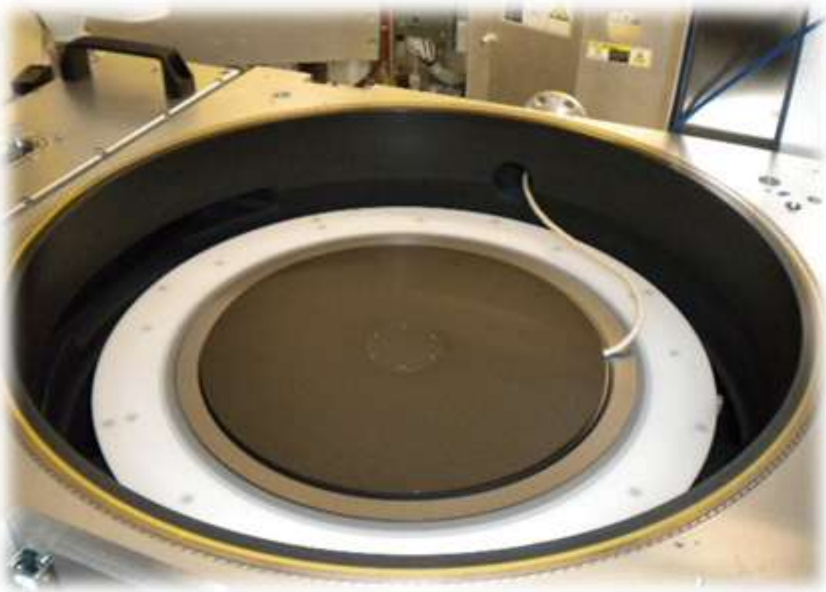
The Semion System Structure

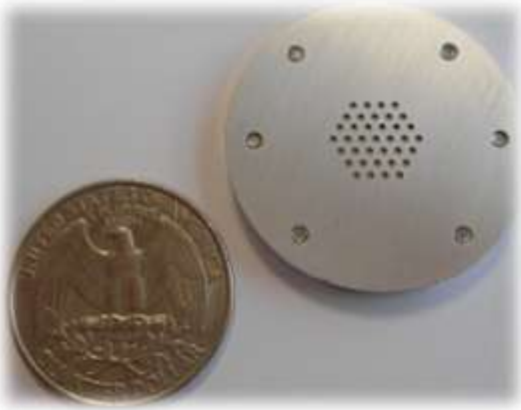
- Electronics Software Unit
- Vacuum Feedthrough
- Ceramic Covered cable
- Sensor Holder Plate
- Replaceable Button Probe Sensor

Located at any position in a plasma chamber (biased, grounded or floating electrode)

The Semion System in a Reactor

- Semion System with a 300mm holder plate, located on the biased electrode driven at 13.56 MHz in a commercial CCP Reactor.





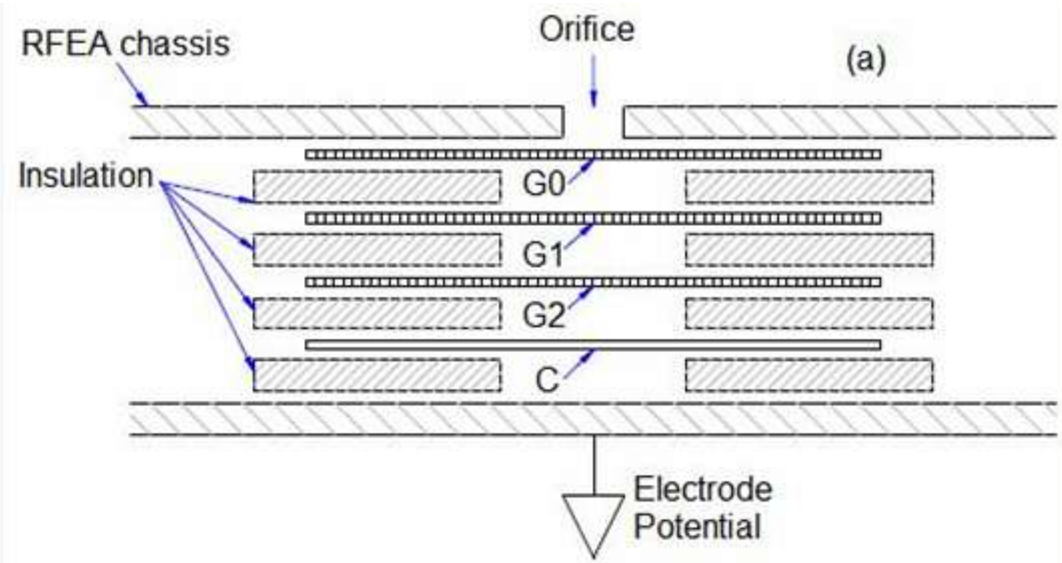
The replaceable Button Probe Sensor is 32mm in Diameter and Sits in a Sensor Holder

The Semion System

"The Semion System was developed to allow users adjust in real time their plasma input parameters to find the optimum Ion Energy and Ion Flux for their application"

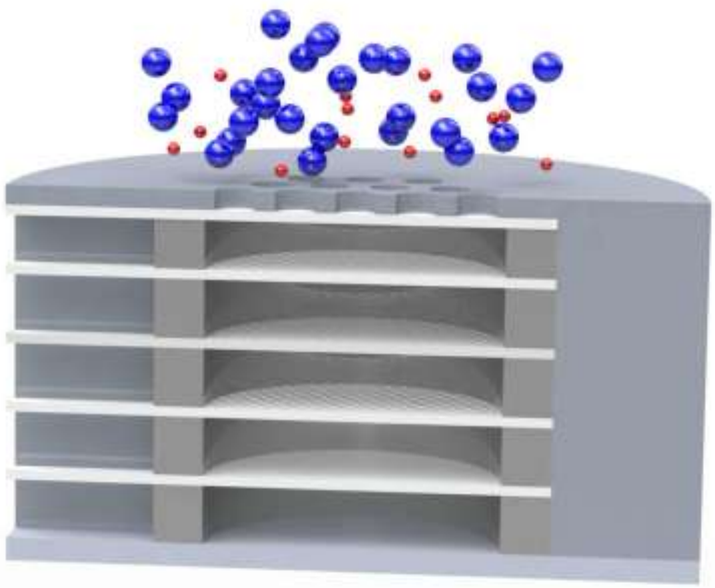
The Grid Structure

- Figure 1(a) show Ions enter the RFEA through an array of sampling apertures exposed to the plasma.



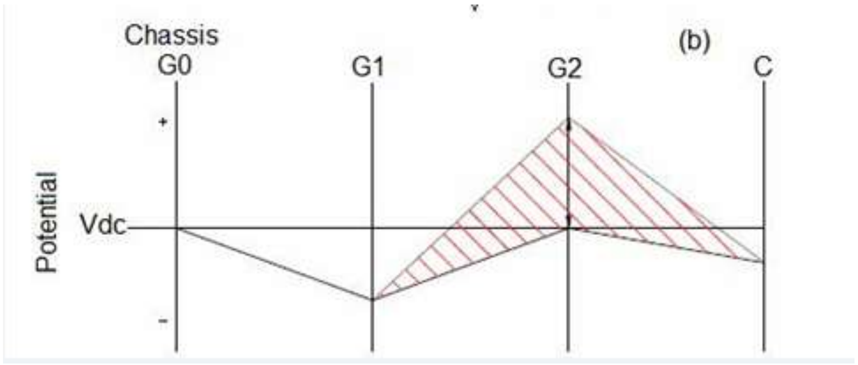
How it Works

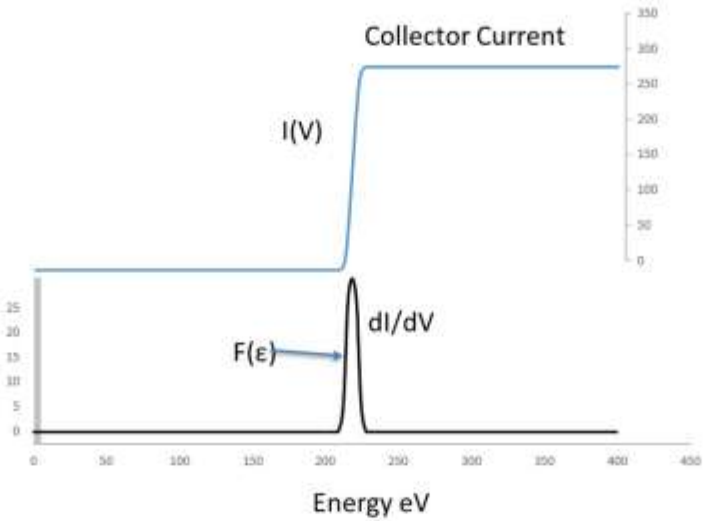
- Grid one prevent the plasma entering the analyser.
- The second grid is biased with a negative potential to repel any electrons.
- A third grid is biased with a positive potential sweep, creating a potential barrier for the positive ions.
- A fourth grid is biased negative relative to collector to repel secondary electrons.
- A collector plate collects the current of ions which cross the potential barrier set by the third grid.



Grid Potential Configuration

- The data acquisition unit records the ion current at each potential applied to G2 and the graphical user interface GUI displays the resultant current-voltage characteristic.
- The IED is also displayed - obtained by differentiation of the current-voltage characteristic.
- The potential distribution is depicted in the upper figure.
- $F(\varepsilon) = \partial I_c / \partial V_{g2}$



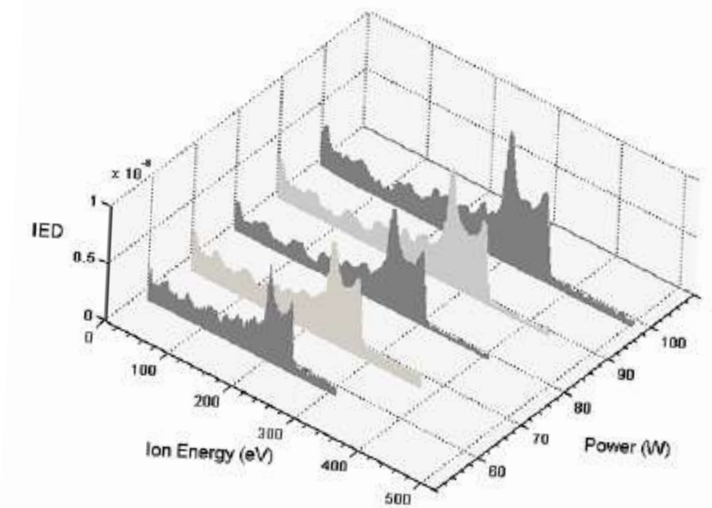


The Semion System

- Measures
  - Ion Energy
  - Ion Flux
  - VDC

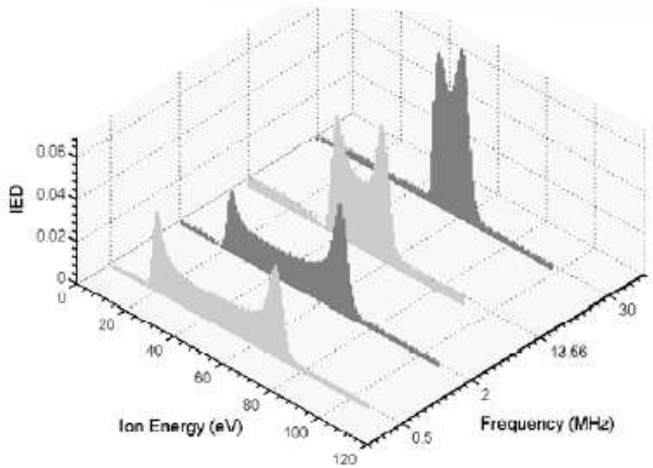
- Located at any position inside a plasma chamber (Biased, Grounded of Floating Position)
- Ion Energy Range 0 to 2500eV
- Time Averaged Resolution (RF System)
- Time Resolved Resolution with a 44nS Time Resolution (Pulsed DC System)

Changing Plasma Input Parameters



Power (W)

- Increasing power can intensify the number of ions hitting the surface and the spread of energy is greatly increased.



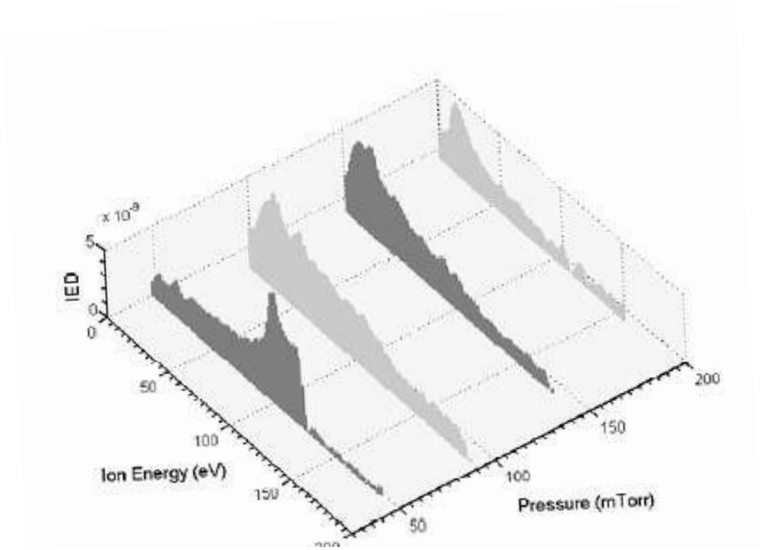
Frequency (MHz)

- By increasing the frequency the spread of the distribution reduces.

Changing Plasma Input Parameters

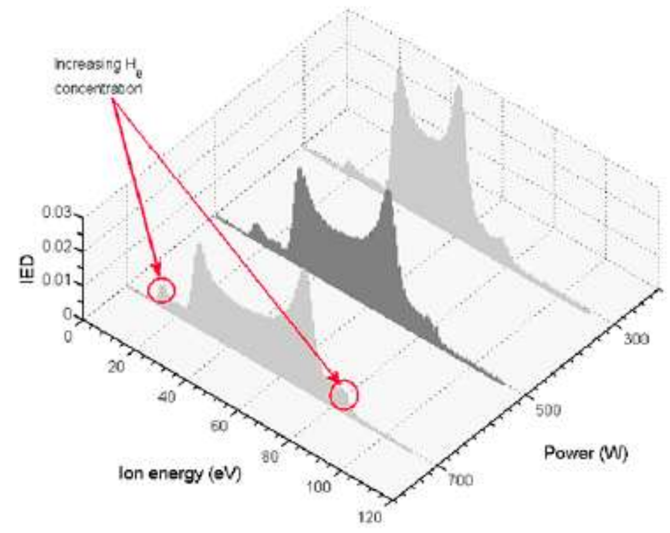
Pressure

- Adjusting the pressure has an effect on the ion energy distribution.



Chemistries

- Different chemistries also have a major effect on the structure of the ion energy distribution.

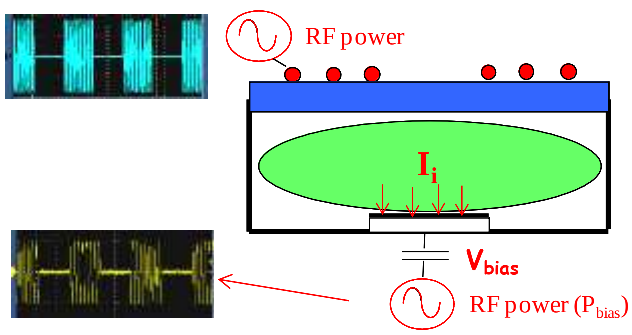


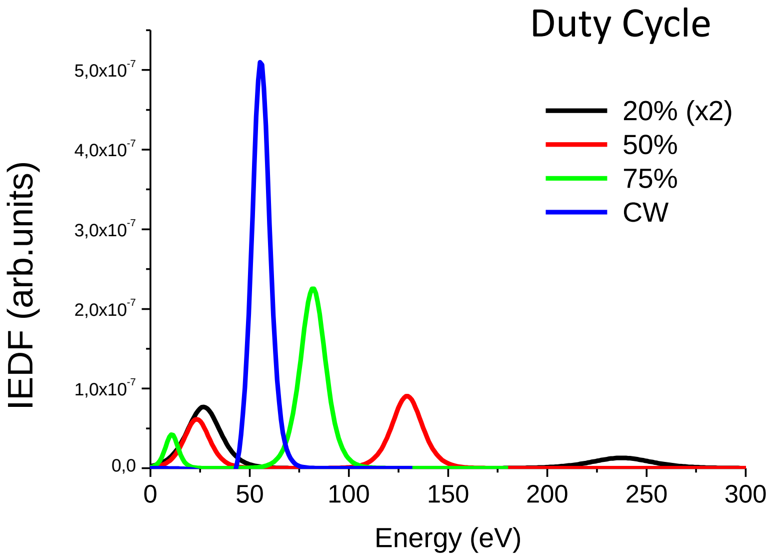
The Semion Pulsed RF Plasma

presented by Gilles Cunge at PPDW 2012

IEDF in <u>synchronous</u> pulsed plasmas (with <u>bias power</u>)

Cl_2 plasma 1000 W / 50 W_{bias} CW or pulsed at 1 kHz





- Bi-modal IEDF (corresponding to ions from ON and OFF periods)

The ion energy in the ON period increases rapidly when the DC is decreased

Customer Data

The Value of The Semion System

“ The Semion System helps users confirm models, optimise processes and produce better results in real time at the substrate position”

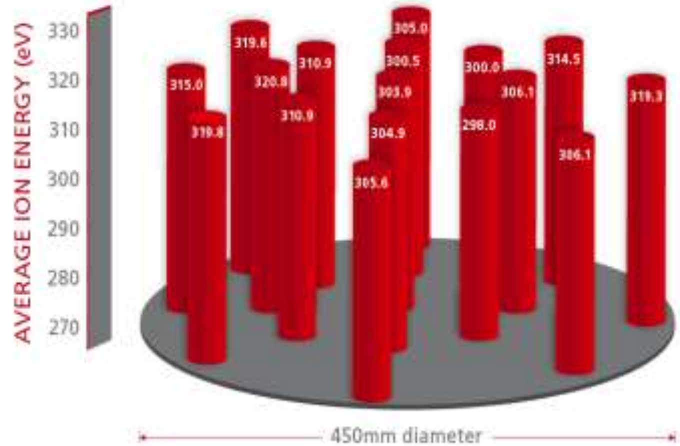
The Semion Spatial System

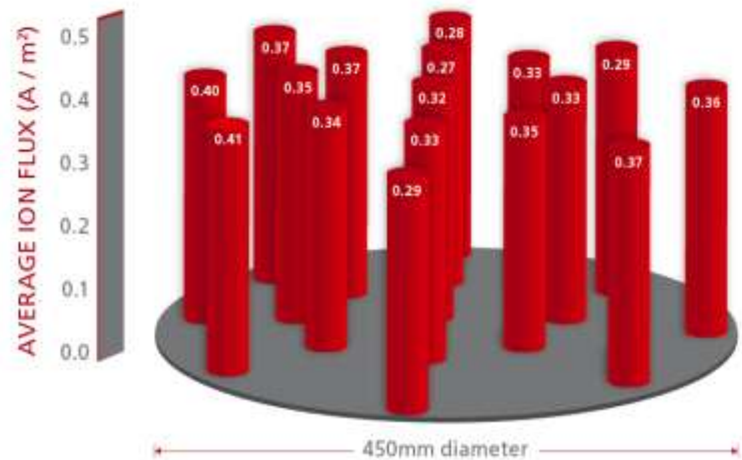
- Measures
  - Ion Energy
  - Ion Flux
  - VDC
  - Spatial Profiling from 13 (300mm) and 17 (450mm) Different Locations

- Located at any position inside a plasma chamber (Biased, Grounded of Floating Position)
- Ion Energy Range 0 to 2500eV
- Time Averaged Resolution (RF System)
- Customised Holders Available

The Semion Spatial

- Ion Energy & Ion Flux Measurement
- 13 Locations (300mm) and 17 locations (450) for Spatial Profiling
- Customisable Shapes and Sizes
- Uniformity Measurement



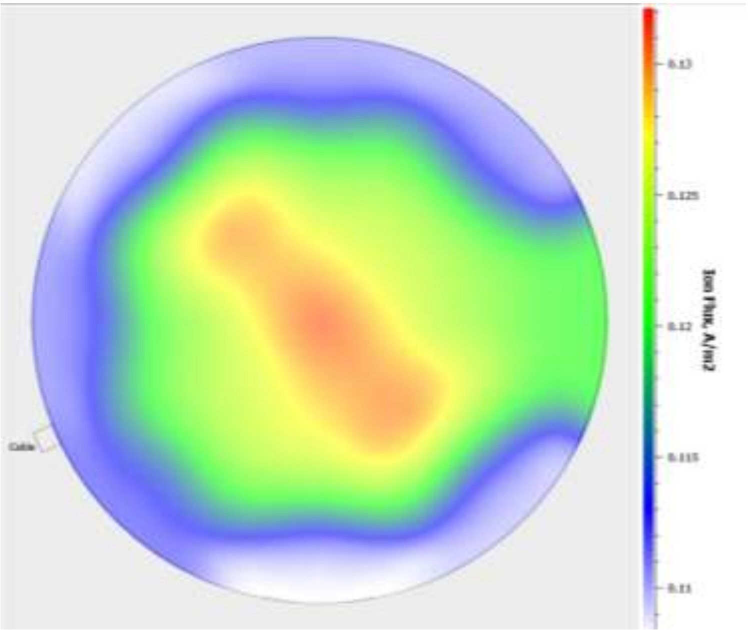


The Semion Spatial 300mm and 450mm

The key issues for 450mm Etch system development are likely to be driven by

- Plasma uniformity, driven by ion flux and energy.
- Radical distributions driven by gas mixtures and electron energy distributions.
- Plasma stability
- Plasma induced damage
- Process performance (Etch Rate, Selectivity, etc..)

Ion Flux



The Semion Spatial 300mm and 450mm

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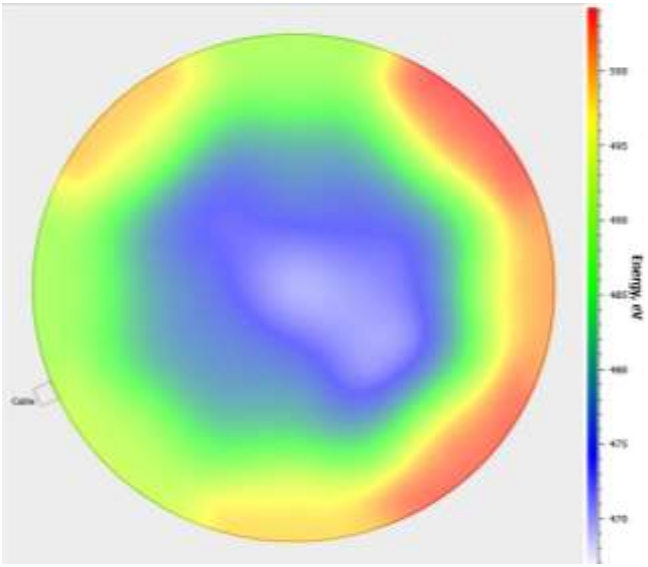
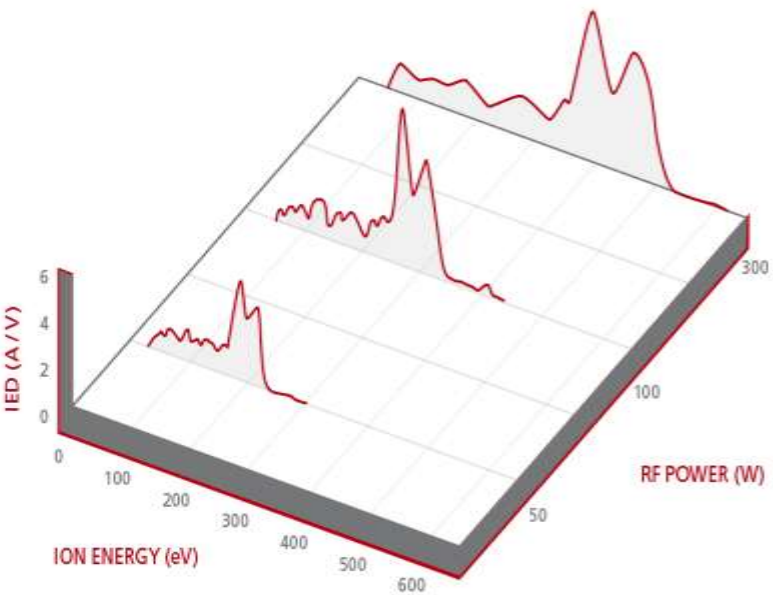
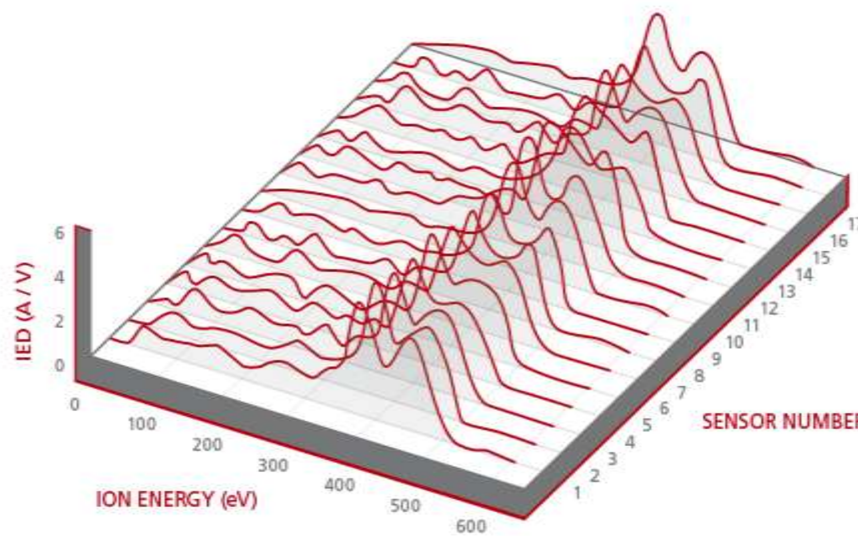
Ion Energy



The Semion Spatial
300mm and 450mm

Ion Energy





Recent advancement of the
Retarding Field Energy Analyzer

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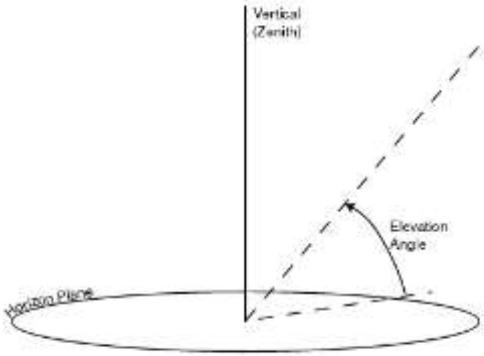
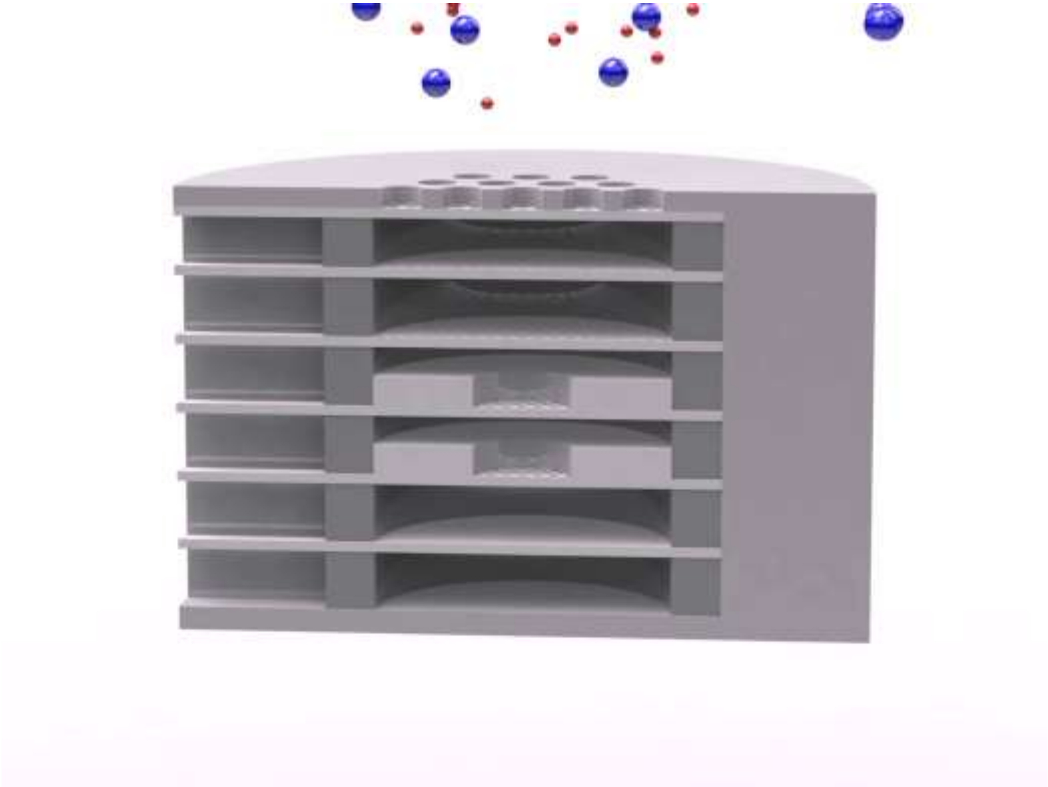
Plasma Measurement

The Semion Angle

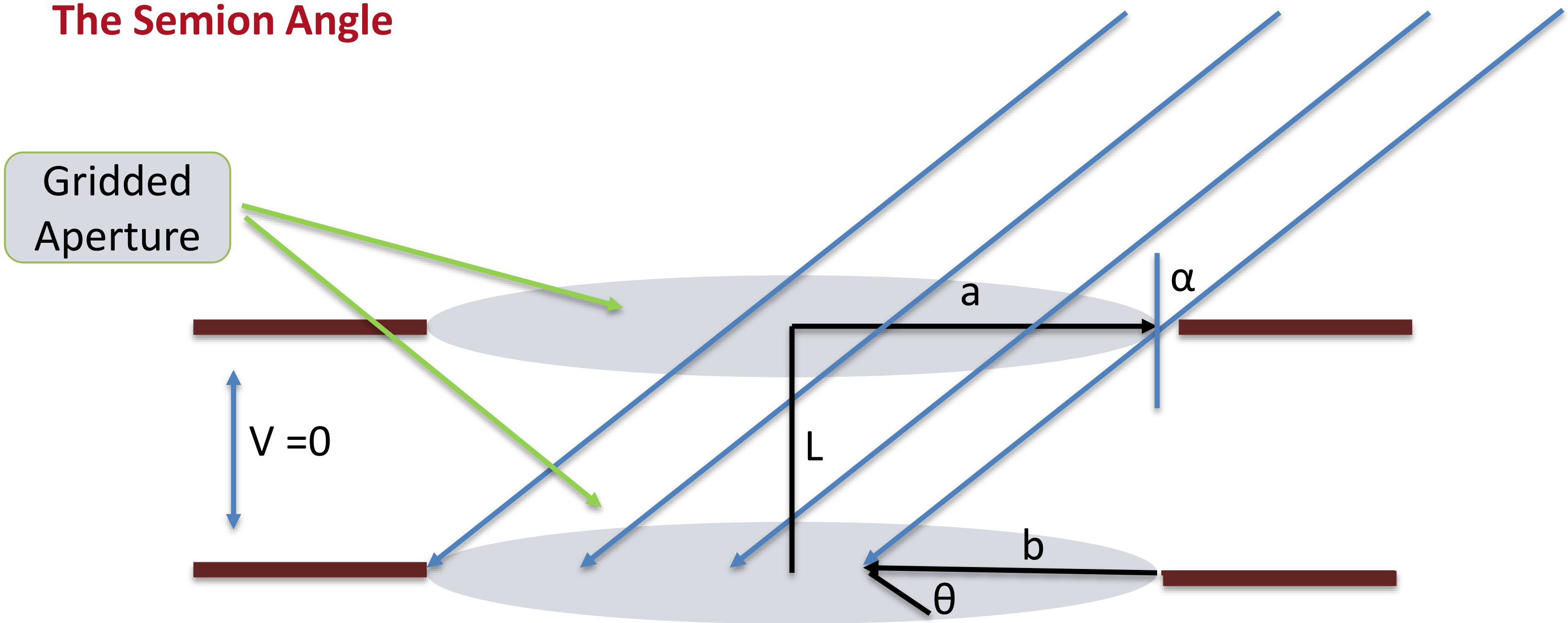
- Elevation Angle
- Ion Energy
- Ion Flux
- Ion Energy & Ion Flux as a Function of Elevation Angle





Angle of Ion’s Hitting the Substrate Position

The Semion Angle

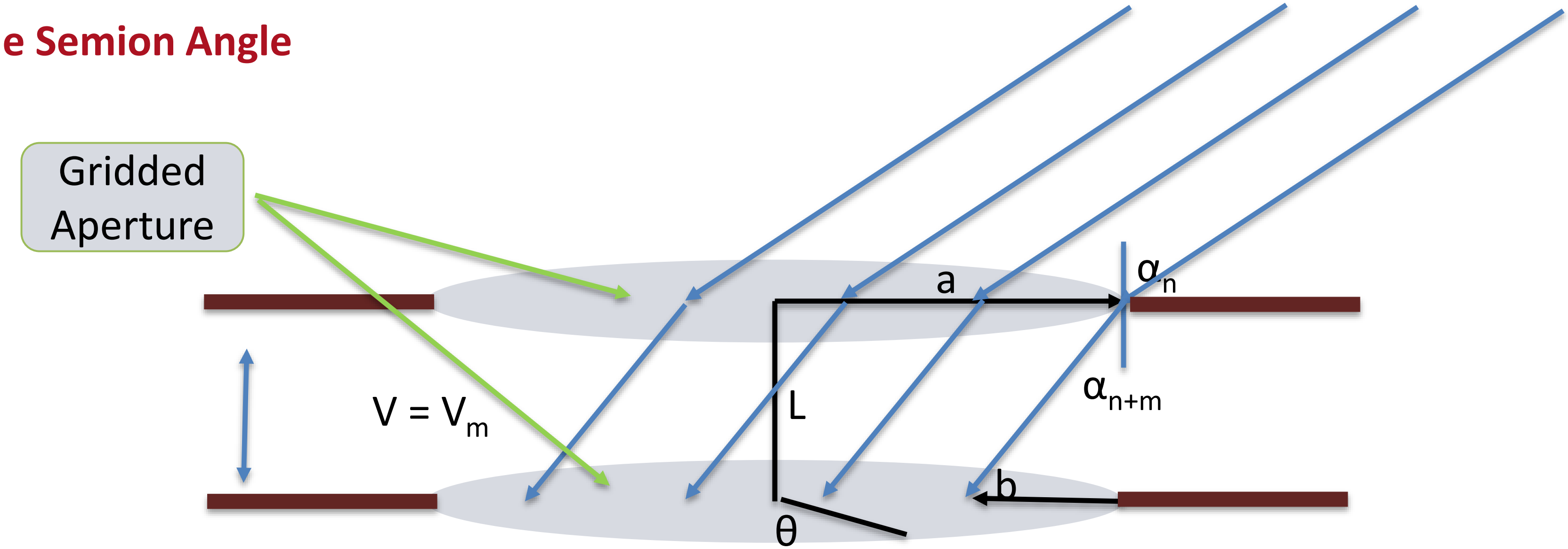


The Current I arriving at the bottom electrode when there is no potential between the grids is defined as;

$$I(\alpha) = \int_0^{a} \int_0^{2\pi} f(\alpha)\, \alpha \, d\alpha \, d\theta + \int_0^{a-b} \int_0^{2\pi} f(\alpha)\, \alpha \, d\alpha \, d\theta$$

$$I = \int_0^{\tan^{-1}(\frac{2a}{L})} f(\alpha)[2\pi a^2 + \pi L 2 tan^2(\alpha) - 2\pi a L \tan(\alpha)] d\alpha$$

The Semion Angle



Chose $\alpha_n = \tan^{-1}(a/L\ k^n)$ where k is arbitrary number 1>k<2 and let L=a

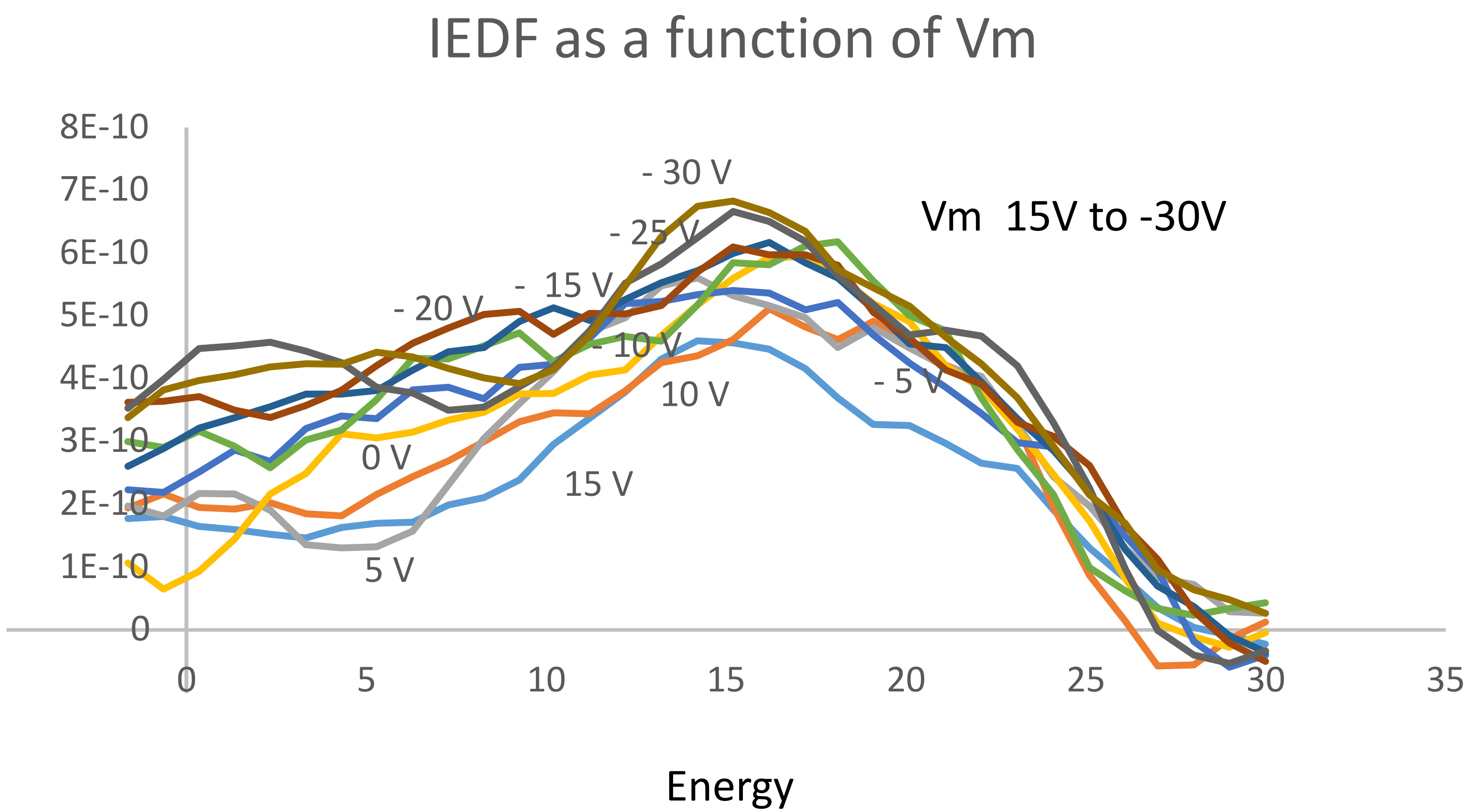
$\alpha_n = \tan^{-1}(1/k^n)$ we can replace the previous integral with a set of discrete functions

$I = \sum_{n=0}^{n=N} f(\alpha_n)\, A_n$ (where A_n are known, see integral)

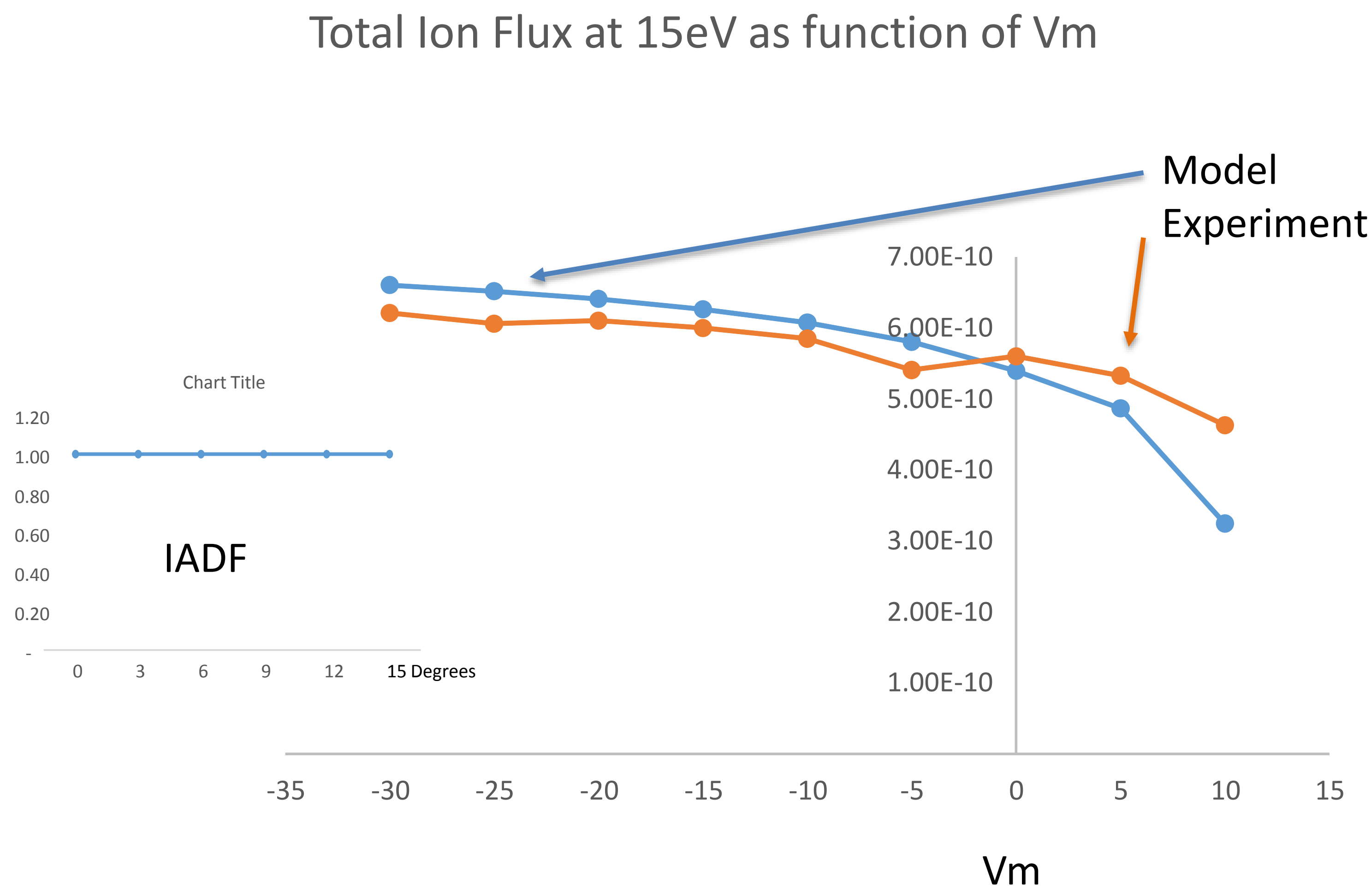
Chose a discrete set of voltages $V_m = V_{m-1}\, k$ so that for each value of V_m the angle between the grids becomes $= \alpha_{n+m}$

We can now vary V_m so that;

$\sum_{m=0}^{m=M} I(Vm) = \sum_{m=0}^{m=M} \sum_{n=0}^{n=N} f(\alpha_n)\, A_{n,m}$ M >= N This is straight forward to solve and to obtain the magnitude of current at each angle segment α_n .


IEDF as a function of Vm
Vm 15V to -30V
8E-10
7E-10
6E-10
5E-10
4E-10
3E-10
2E-10
1E-10
0
0
5
10
15
20
25
30
35
Energy
- 30 V
- 25 V
- 20 V
- 15 V
- 10 V
- 5 V
0 V
5 V
10 V
15 V

The Semion Angle



Angle of Ion's Hitting the Substrate Position

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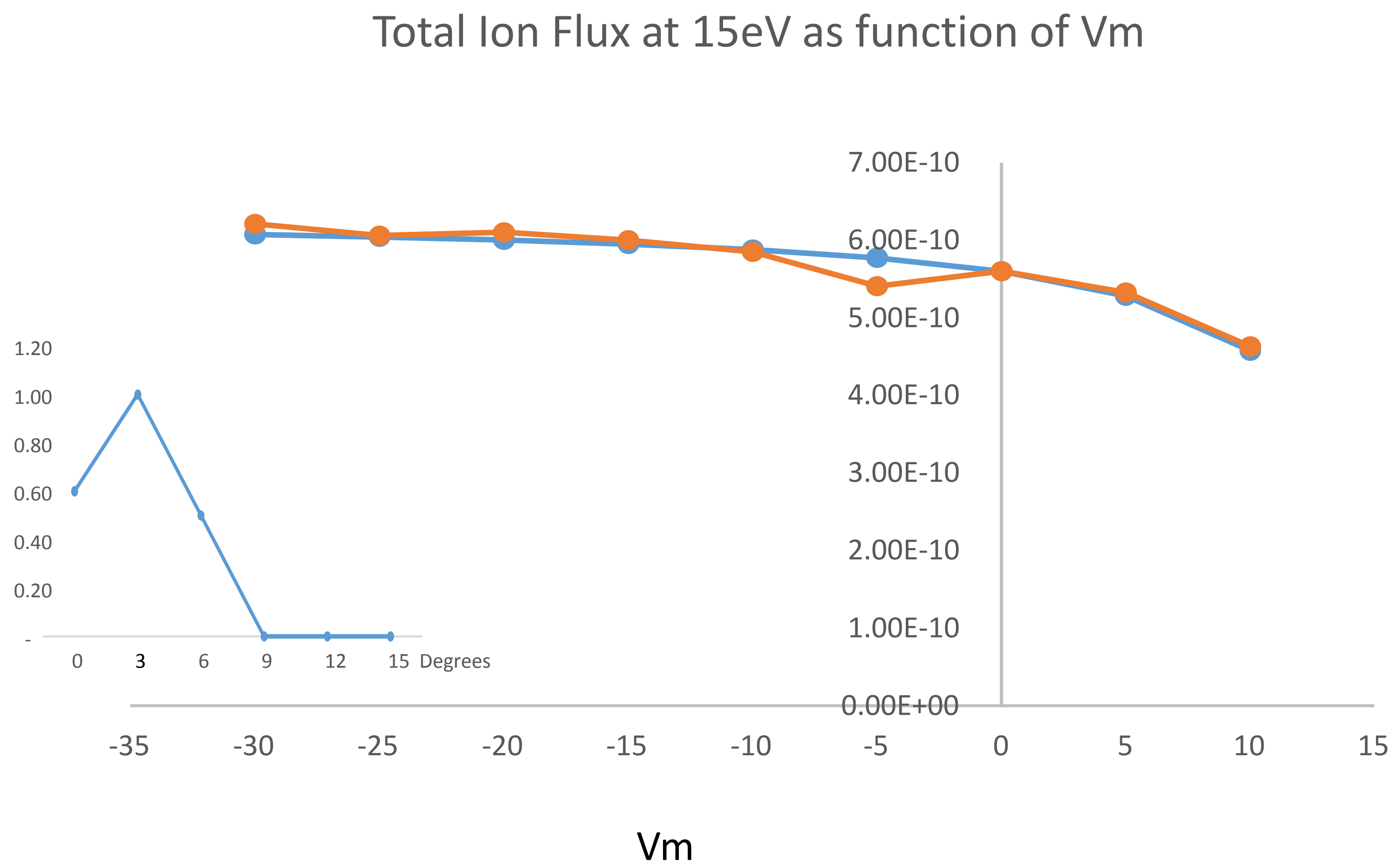
Plasma Measurement

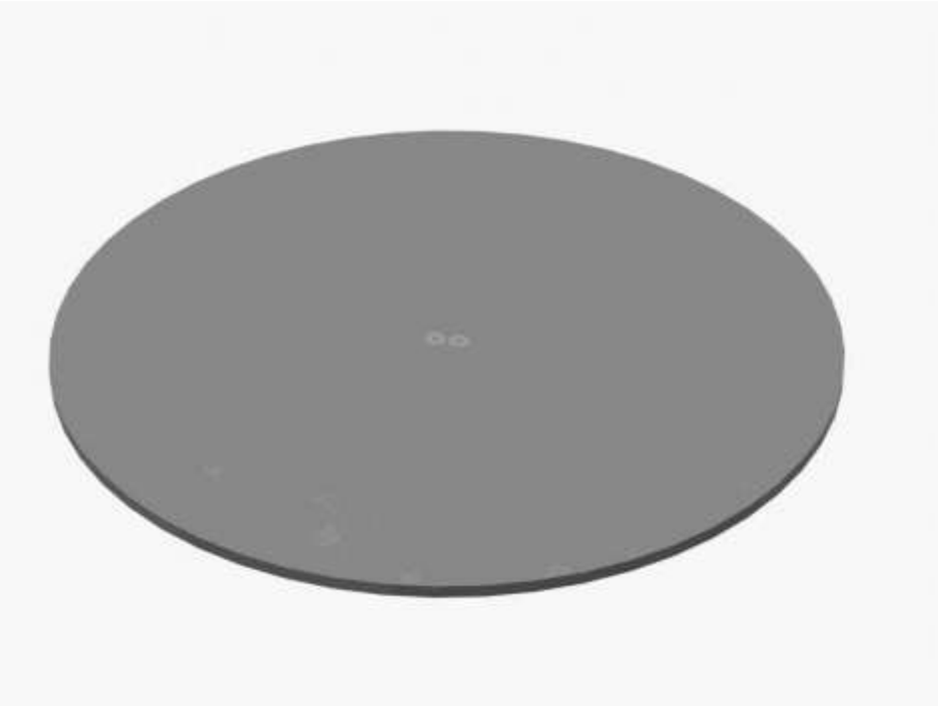
The Semion Angle



Angle of Ion's Hitting the Substrate Position

The Semion Quartz Crystal

- Deposition Rate
- Ratios between Neutrals & Ions
- Ion Energy & Ion Flux
- Deposition Rate as a function of Ion Energy & Ion Flux



QCM

The System can sit on a biased electrode and can operate in temperatures up to 250^{o} C without the need for cooling.

Embedded Quartz Crystal on the Electrode

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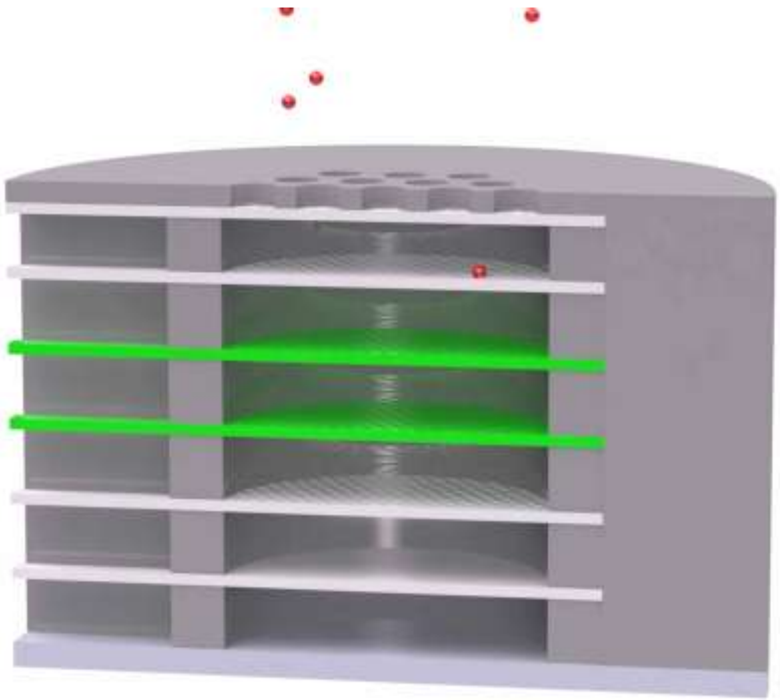
Plasma Measurement

The Semion Mass



- Mass Resolved
- Ion Energy
- Ion Flux
- Ion Energy & Ion Flux as a Function of mass

The System can sit on a biased electrode and can operate in temperatures up to 250° C without the need for cooling.

The Semion Mass

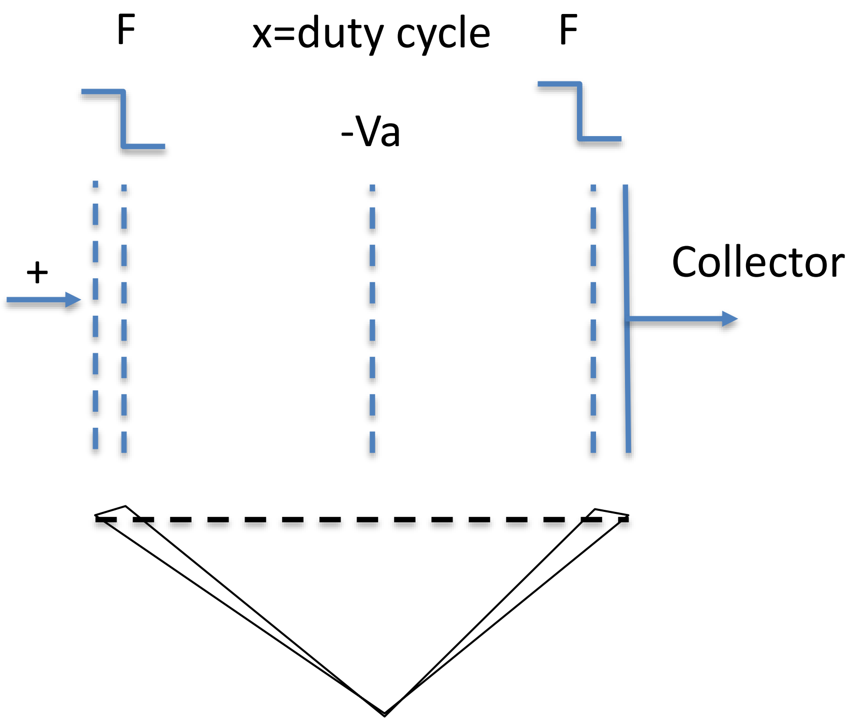
When F is high ions are stopped entering and exiting discriminator

When F is low for x% of time, ions can freely pass into and exit the discriminator

$$< Ia > = I.\left(\frac{time\ ions\ flowing}{total\ time}\right)$$

$$< Ia > = I.\left(\left(\frac{x}{F} - td\right) \Big/ \left(\frac{1}{F}\right)\right)$$

$$< Ia > = I.F.\left(\frac{x}{F} - td\right)$$

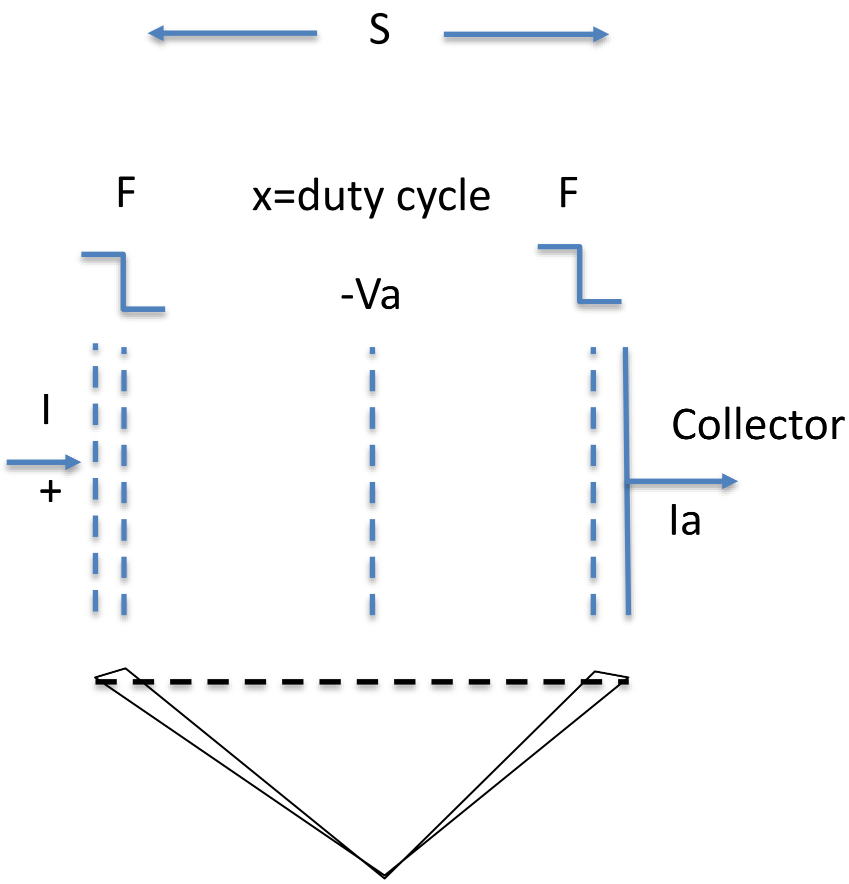


The Semion Mass

$$V = {}^{S}/_{td} = \sqrt{2eVa/m}\,/_{2}$$

$$td = (2S\sqrt{m})/\sqrt{2eVa}\,)$$

$$< Ia > = I.F.\left\{\frac{x}{F} - (2S\sqrt{m})/\sqrt{2eVa}\,\right)\right\}$$



$$< Ia > = I.F.\left\{\frac{x}{F} - (2S\sqrt{m})/\sqrt{2eVa}\,\right)\right\}$$

$$< Ia > = 0 \text{ when } \frac{2S\sqrt{m}}{\sqrt{2eVa}} > x/F$$

The Semion Mass

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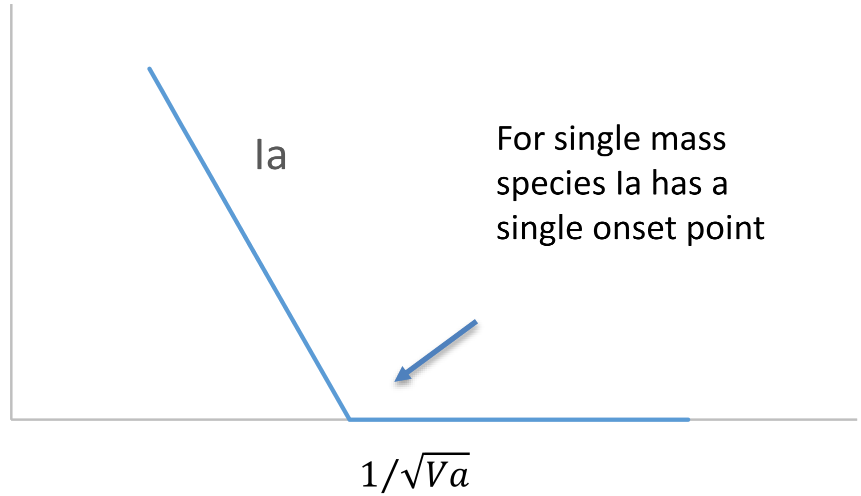
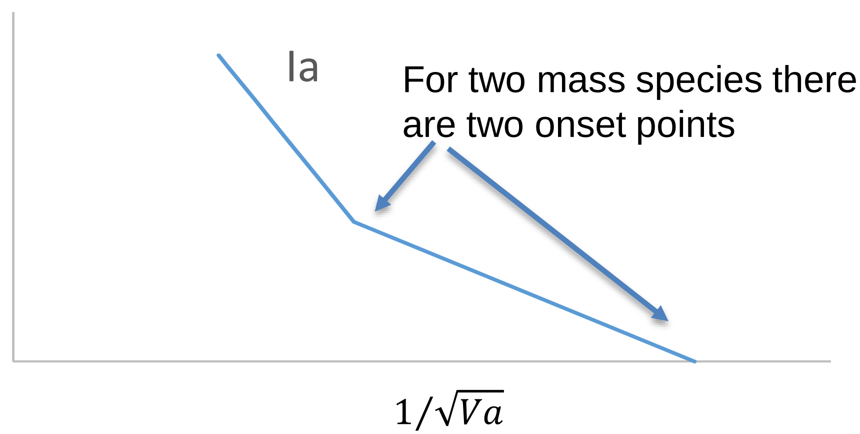


Onset occurs at specific Voltage Va determined by mass of ions

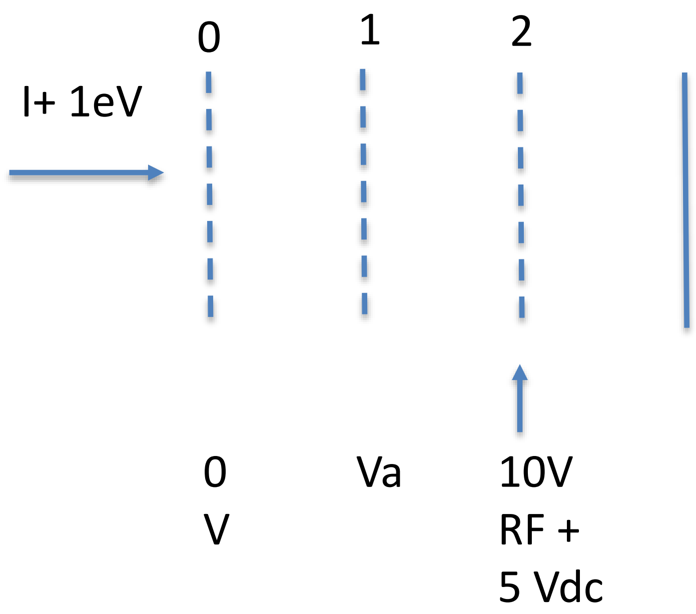
$$\boldsymbol{M} = 2\boldsymbol{x}^2\boldsymbol{Va}\,.\,\boldsymbol{e}/(2\boldsymbol{SF})^2$$

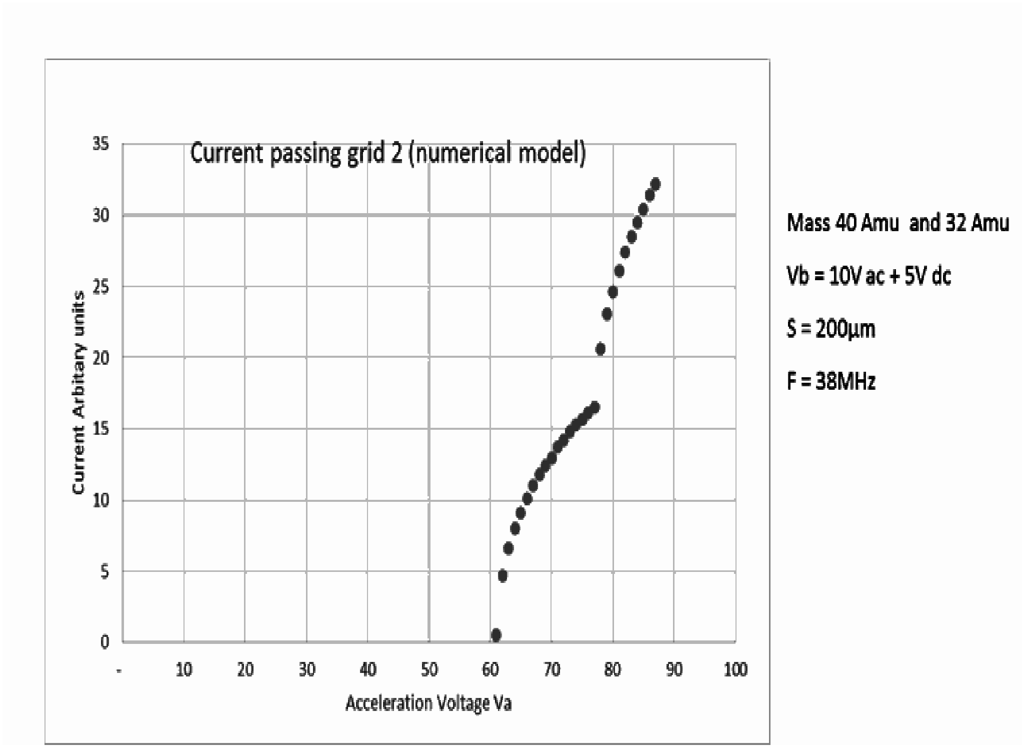
The difference in slope is proportional to flux of particles at that mass



The Semion Mass

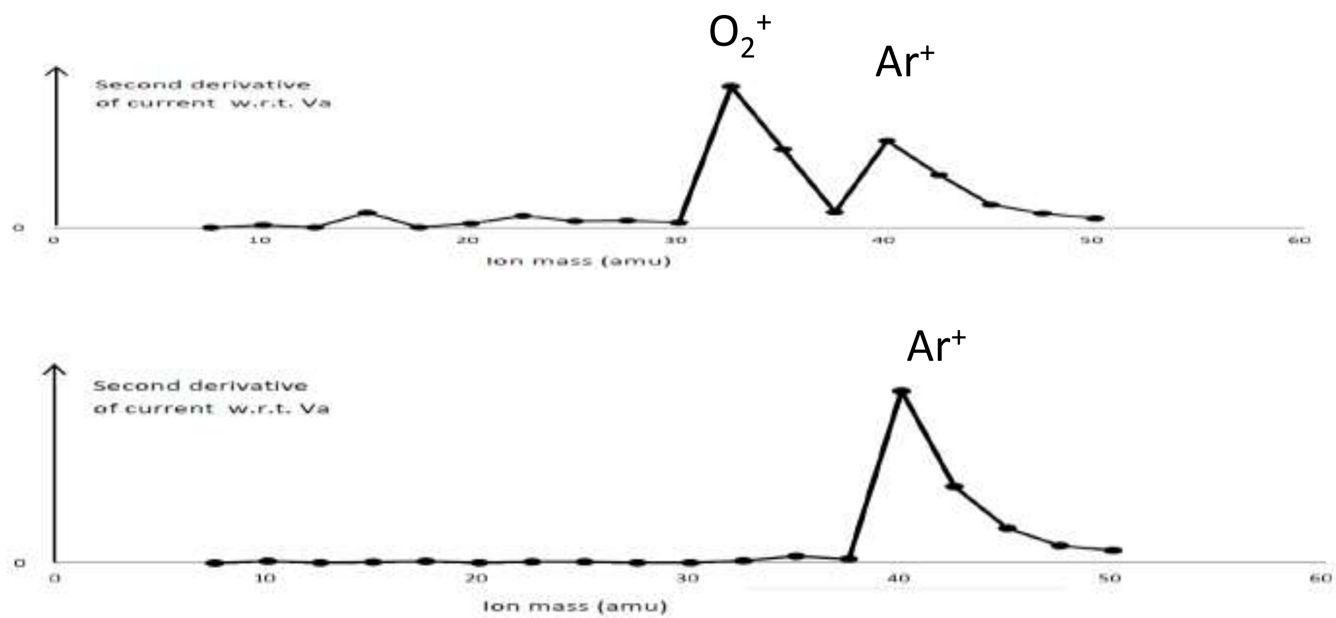
The previous example uses two explicit grids as ion gates but a gate entrance can be between grids and the exit at a grid so that a single pulsed grid can used. The system also works with a sinewave as the bias potential, but we need numerical models to analyse





The Semion Mass

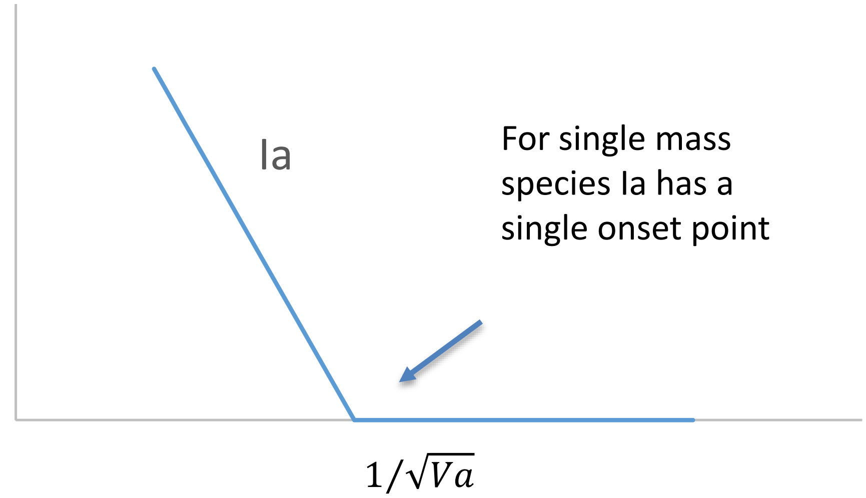
Initial data from an Argon and Argon Oxygen plasma shows that Semion mass can currently resolve to better than 5 AMU. The first product will be released in early 2014.



The Semion Mass

$$< Ia > = I.F.\left\{\frac{x}{F} - (2S\sqrt{m})/\sqrt{2eVa}\ )\right\}$$

$$< Ia > = 0 \text{ when } \quad \frac{2S\sqrt{m}}{\sqrt{2eVa}} > x/F$$



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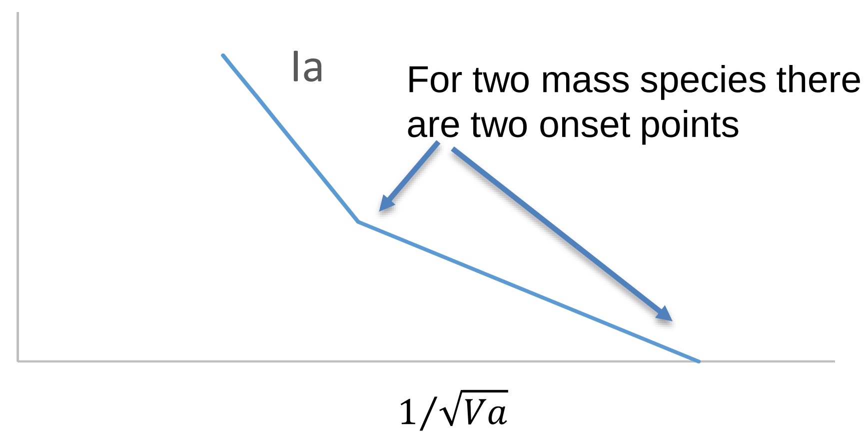
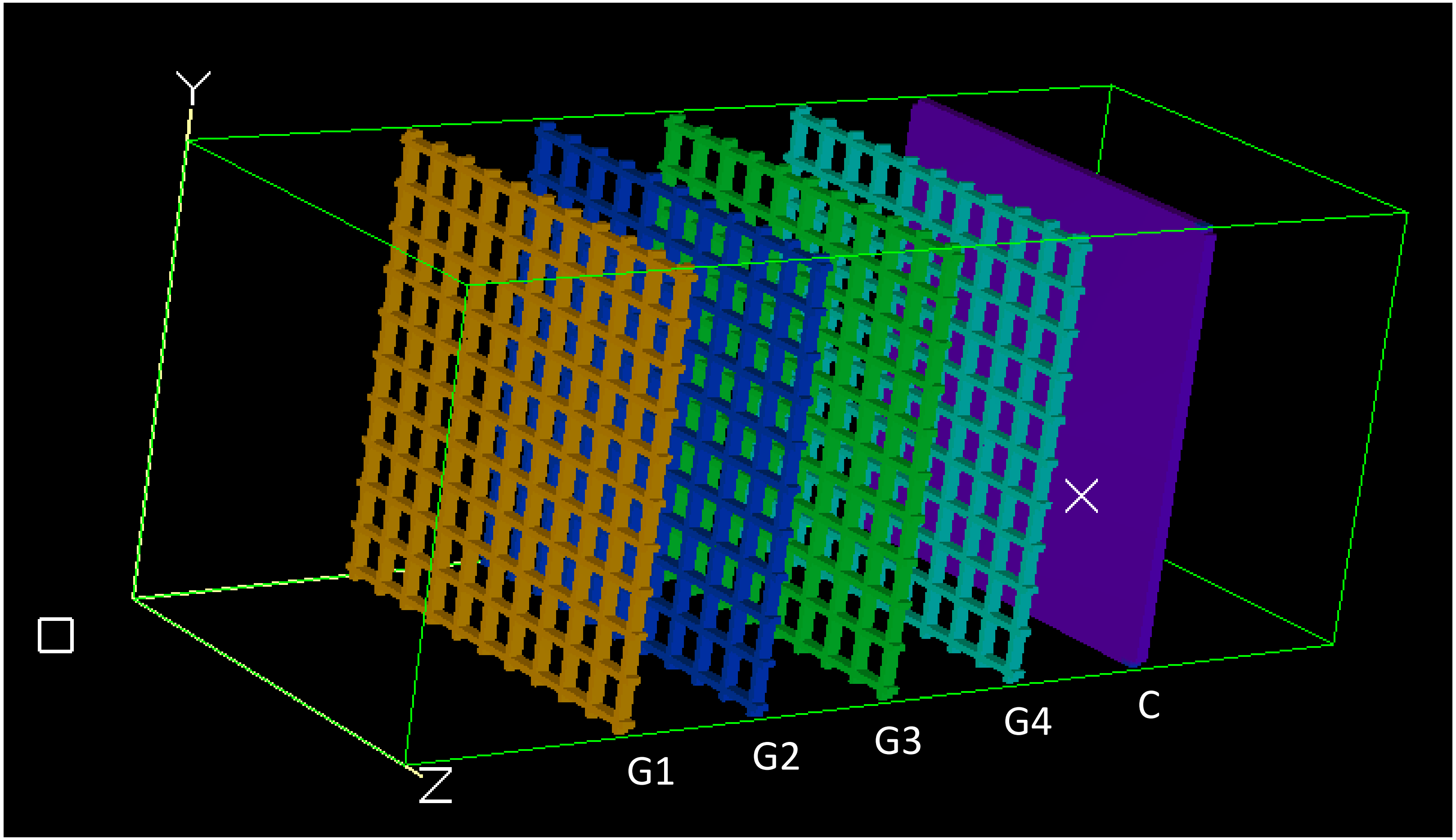


Grid Structure Layout:

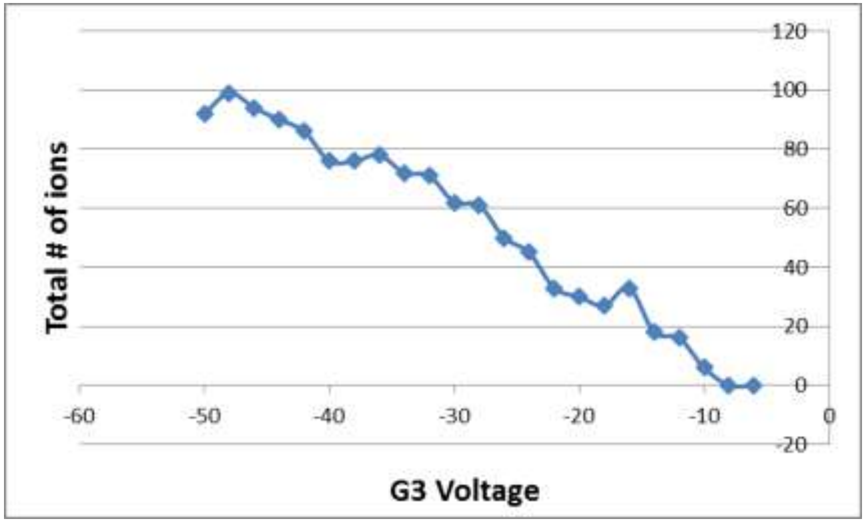


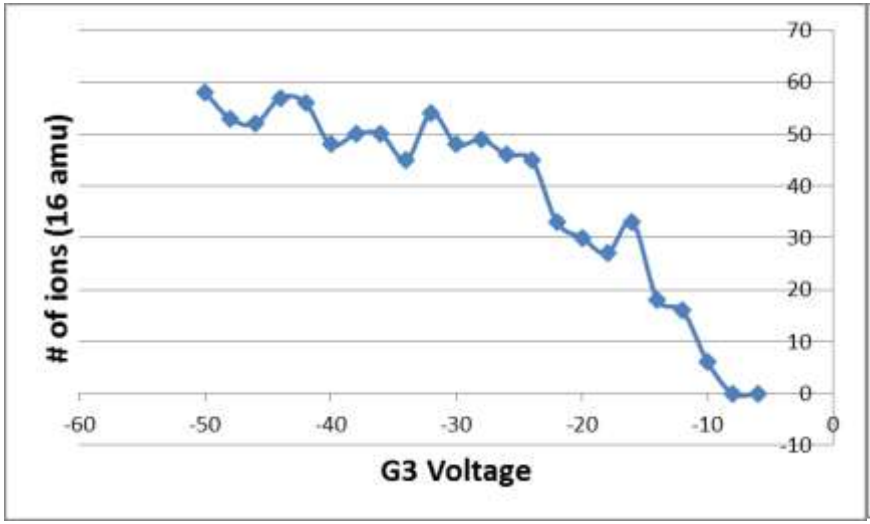
Experimental conditions:

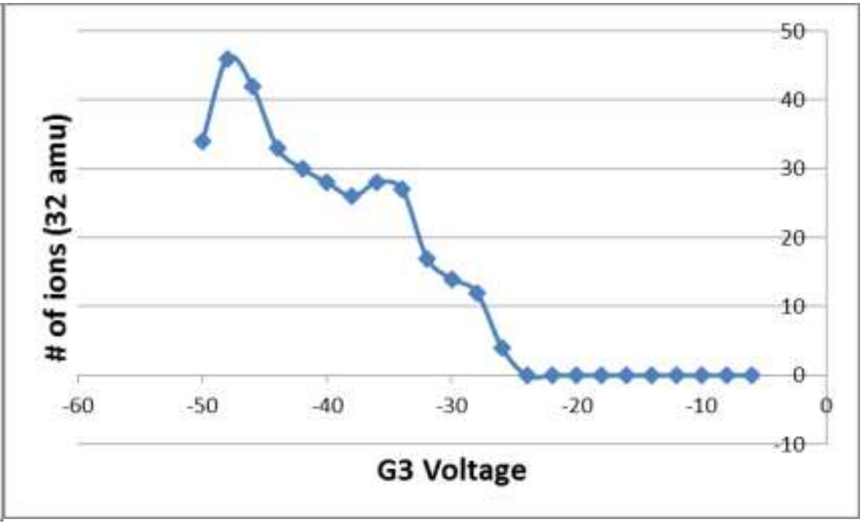
- Grid Transmittance: 70 %
- Spacing b/w grids: 200 µm
- G1 voltage: 0 V (floating with chassis)
- G2 voltage: -60 V DC
- G3 voltage: 0 to -50 V DC (sweep-in voltage)
- G4 voltage: 17 V DC + RF (@10 V Amplitude and 38 MHz)
- Collector voltage: -60 V DC
- Ion energy: 12 eV
- Ion mass: Group 1 (16 amu) + Group 2 (32 amu)

Simulation Results:

- # of ions flown = 500 (250 each)
- G3 voltage step size = 2 V



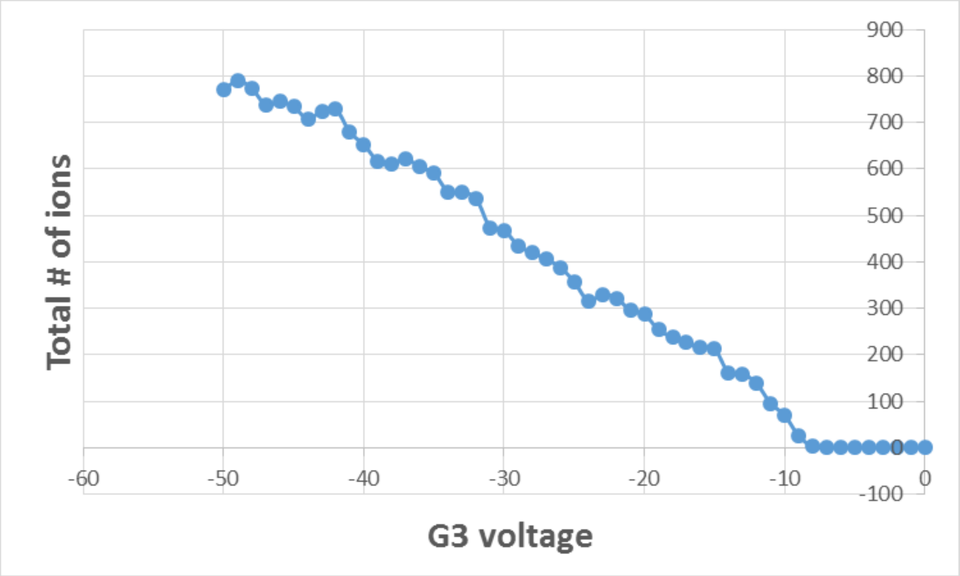


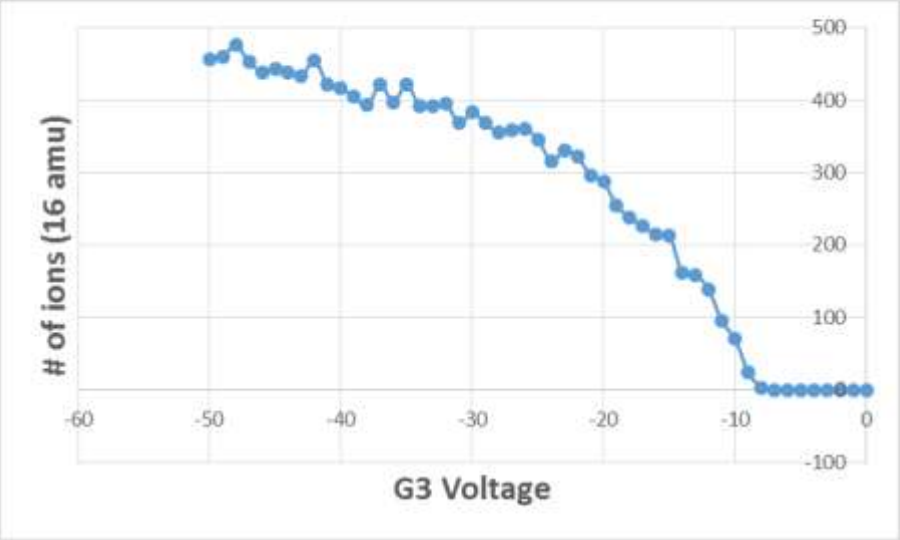


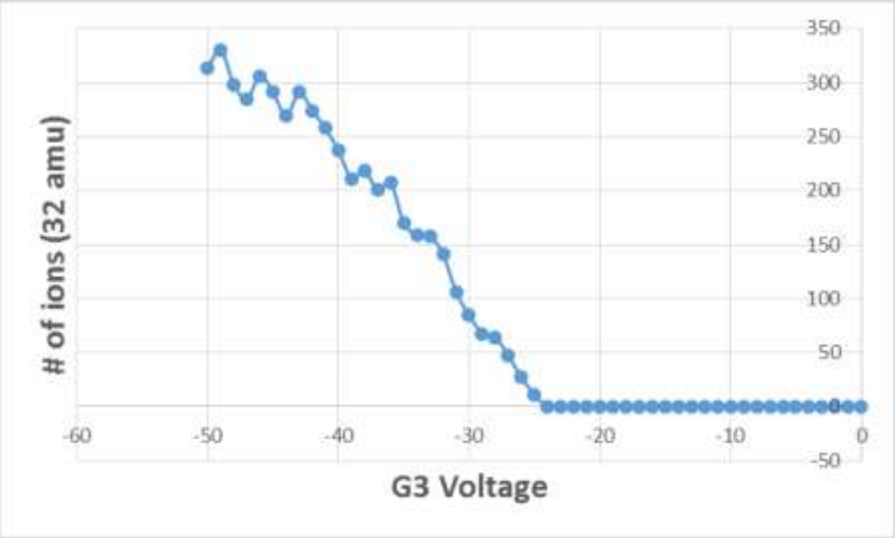
The Semion Mass

Simulation Results:

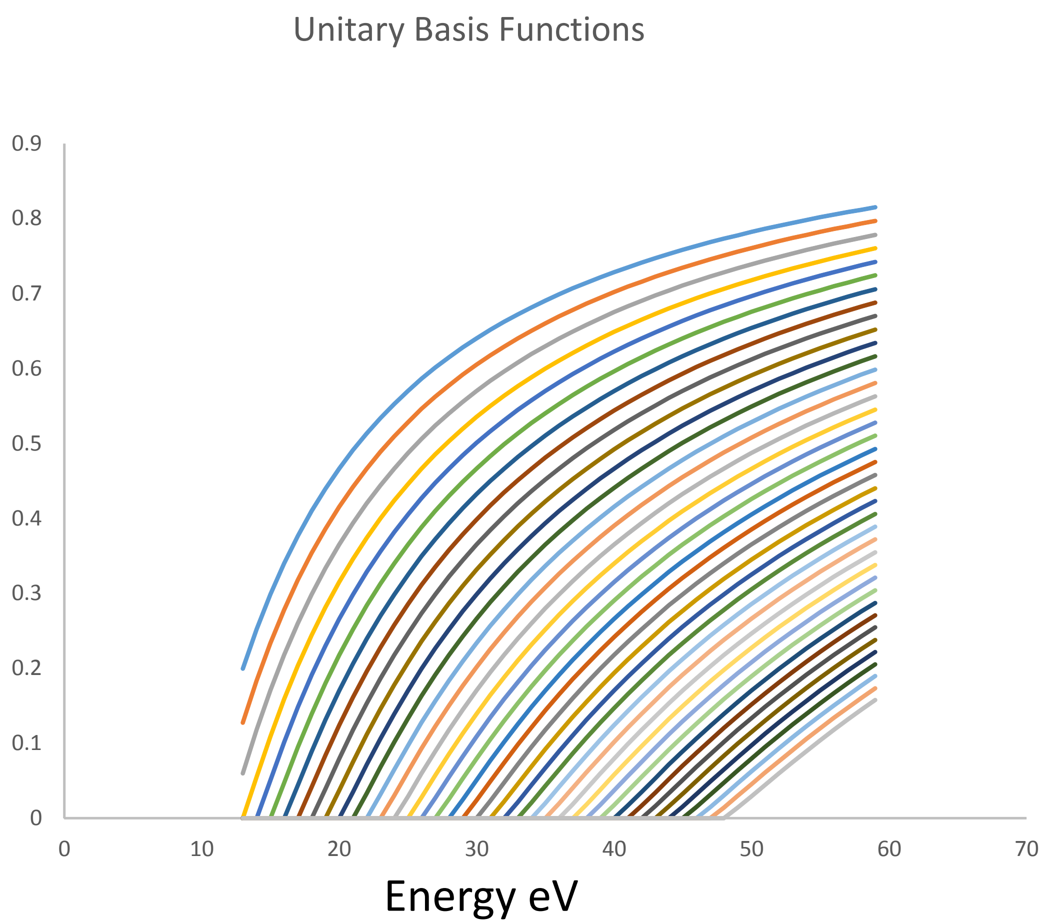
- # of ions flown = 4000 (2000 each)
- G3 voltage step size = 1 V



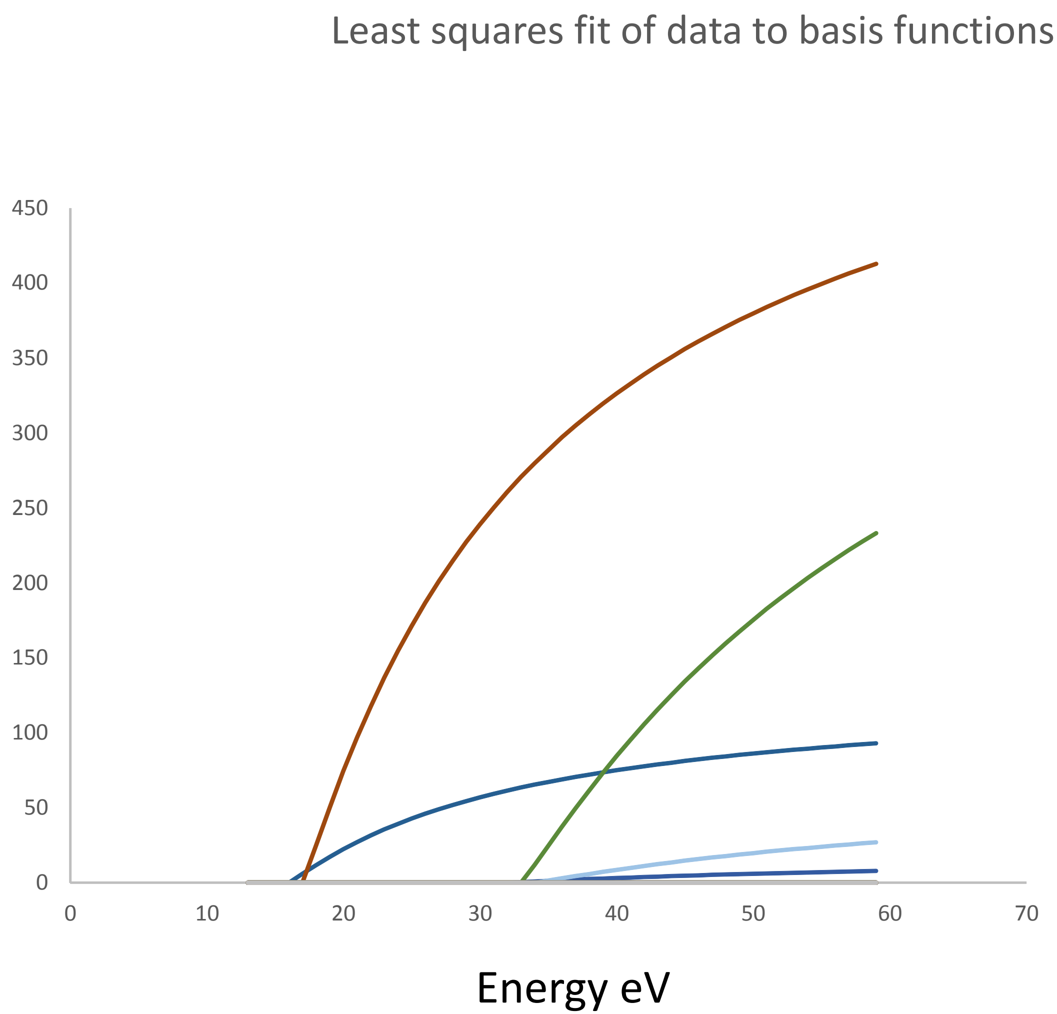




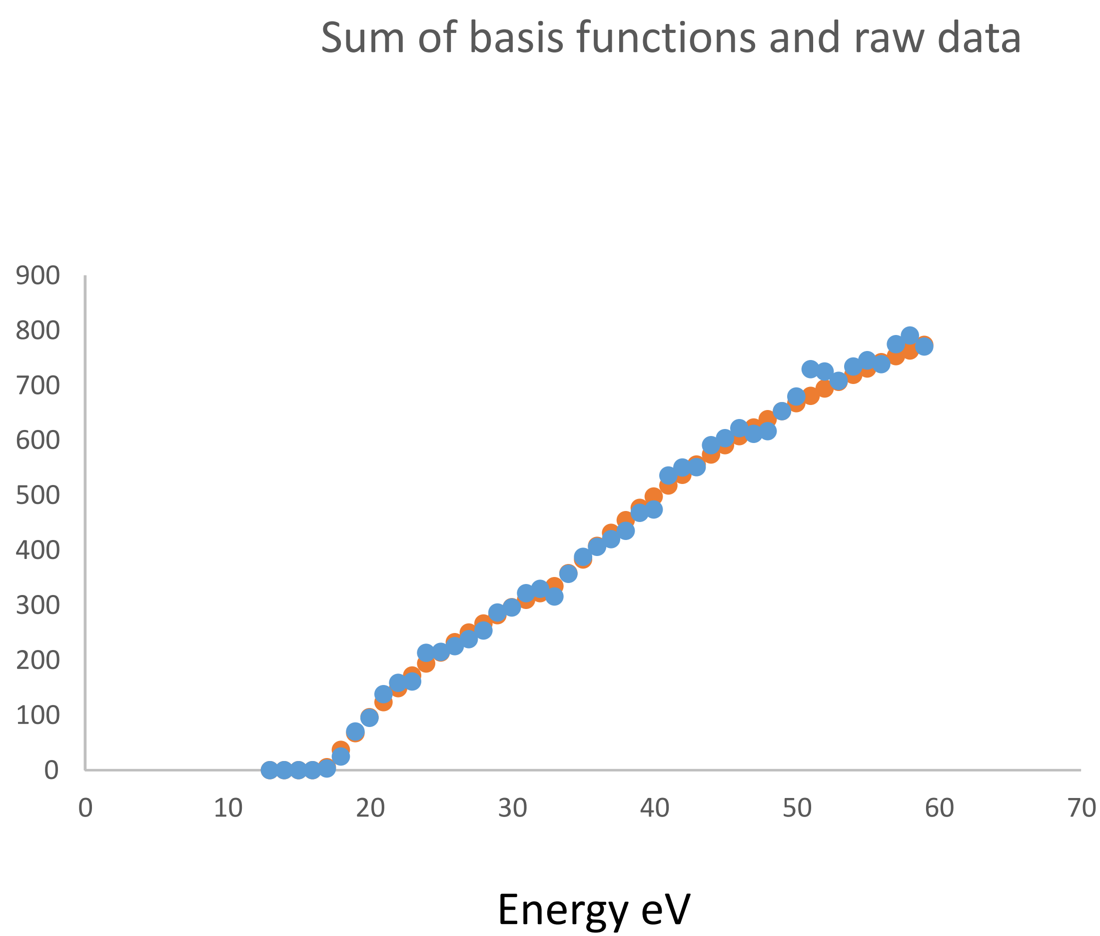
The Semion Mass



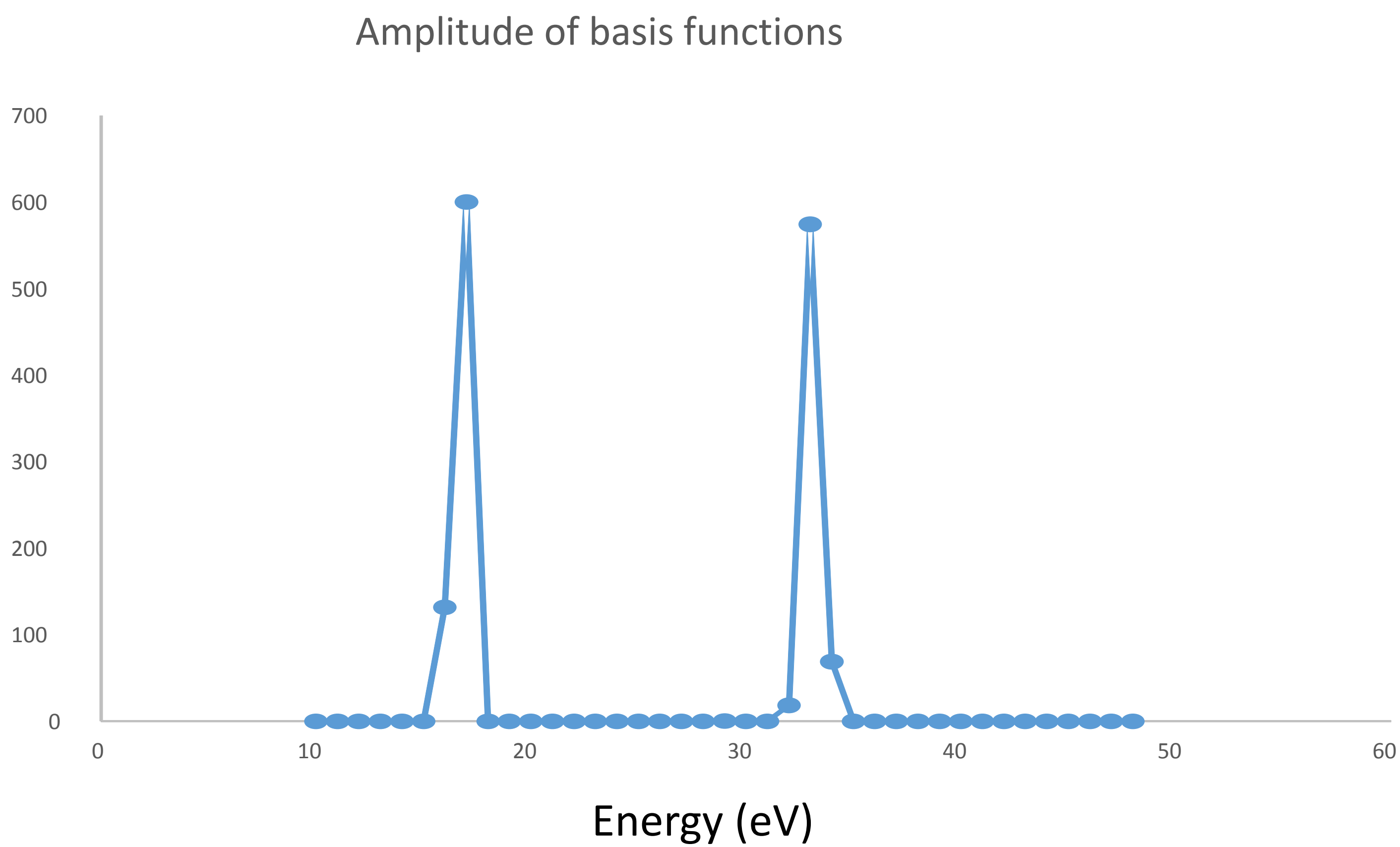
The Semion Mass



The Semion Mass



The Semion Mass



Proposal for wireless measurement at the substrate

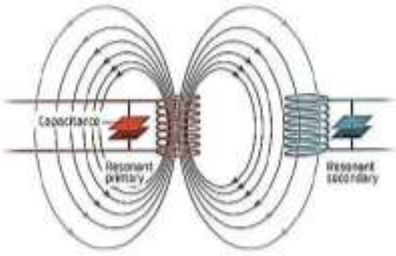
Impedans
Plasma Measurement

Wireless Sensors

RFID Tags

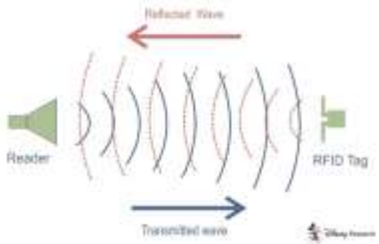
Near field (LF, HF): inductive coupling of tag to magnetic field circulating around antenna (like a transformer). Varying magnetic flux induces current in tag. Modulate tag load to communicate with reader field energy decreases proportionally to $1/R^3$ (to first order)

Near Field



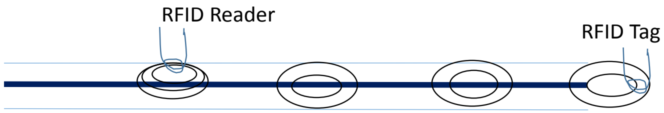
Far field (UHF, microwave): backscatter. Modulate back scatter by changing antenna impedance. Field energy decreases proportionally to 1/R. Boundry between near and far field: R = wavelength/2 pi so, once you have reached far field, lower frequencies will have lost significantly more energy than high frequencies

Far Field



Transmission Line
Energy is coupled into transmission line and data transmitted back via line. No loss of field energy over long distances. Similar to near field without loss. Primarily inductive coupling. Reader does not need to be source of RF energy.

TX Field



Wireless Sensors

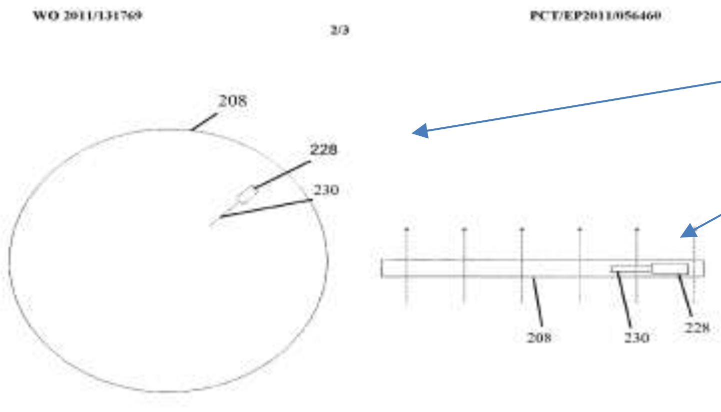


Fig. 2a Fig. 2b

RFID sensor embedded in sensor wafer

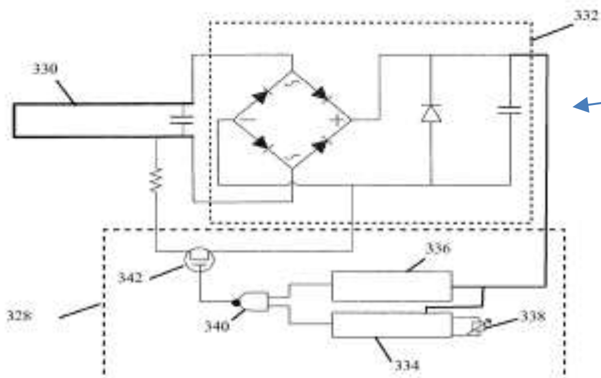


Fig. 3

Scavenges power from RF field and transmits data back through virtual RF transmission line

Wireless Sensors

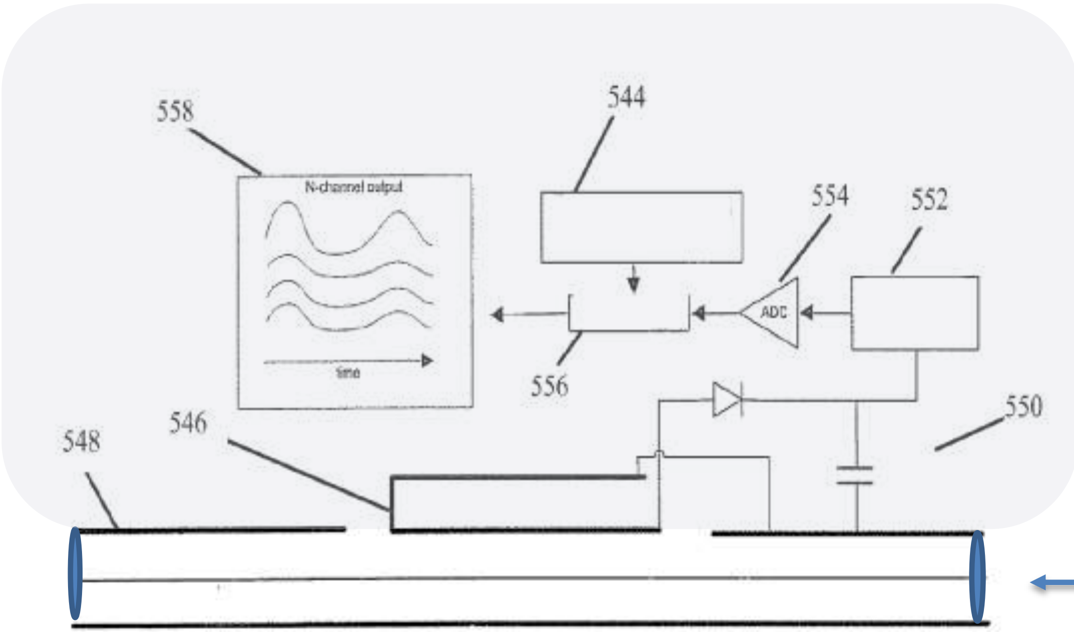


Fig. 5

Receiver of N channels of real time sensor data

RF Power Coax

Wireless Sensors

First stage is to measure

- **Temperature**
- **Ion Flux**
- **Voltage**

Conclusion

Impedans are working with our customers to create a range of plasma measurement systems that helps users confirm models, optimise processes and produce better results in real time at the substrate position.