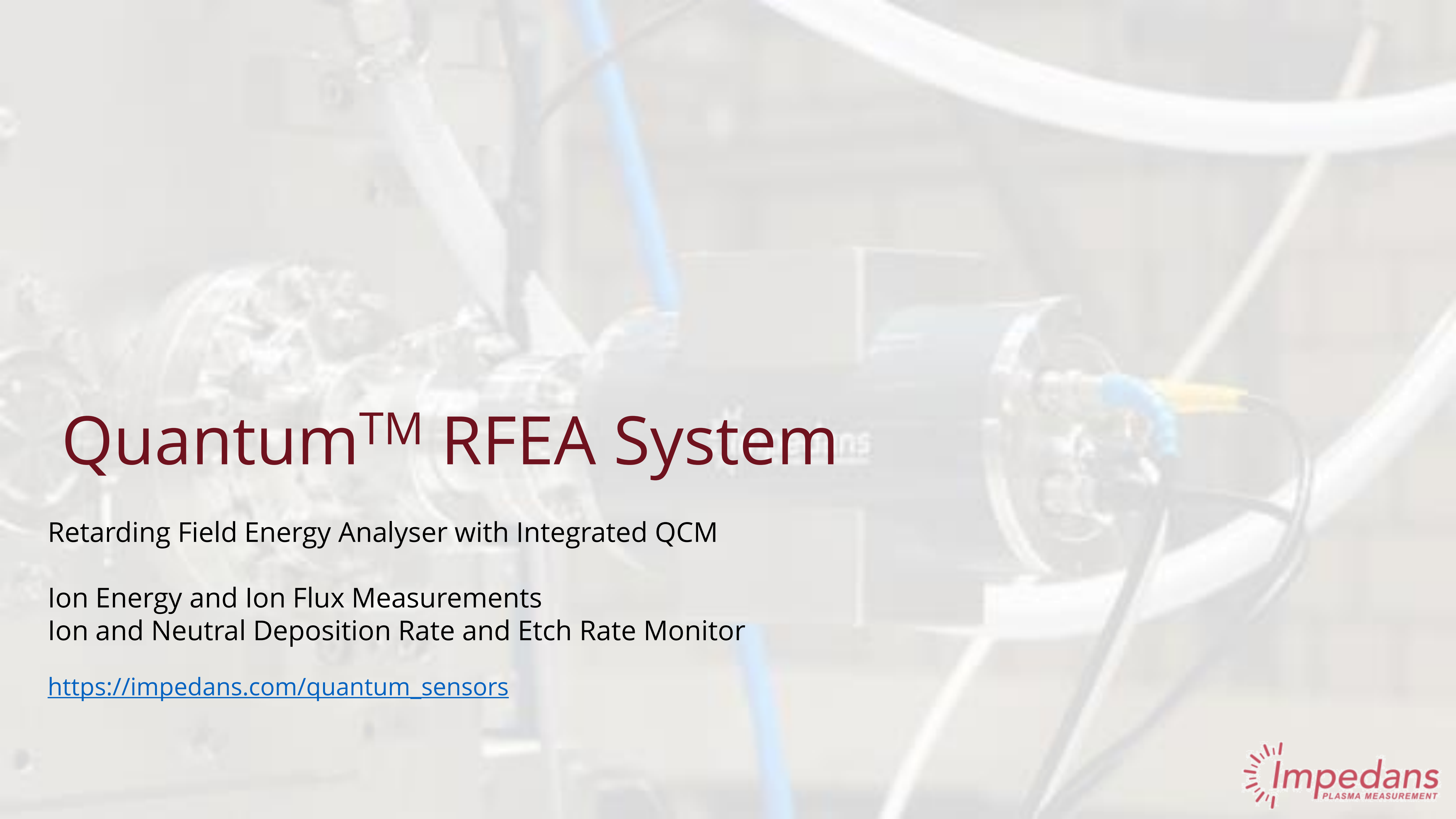


Quantum$^{\text{TM}}$ RFEA System

Retarding Field Energy Analyser with Integrated QCM

Ion Energy and Ion Flux Measurements
Ion and Neutral Deposition Rate and Etch Rate Monitor

https://impedans.com/quantum_sensors

The Quantum System

Suitable for Grounded, Floating, DC, and CW RF biasing; Suitable for pulsed sources with shielding

Parameters Measured:

- ✓ Ion energy distribution function (IEDF)
- ✓ Average Energy & Ion Flux
- ✓ Vdc
- ✓ Ion-Neutral fraction
- ✓ Ion and neutral deposition rates
- ✓ NEW: Ion and radical etch rates

Specification

- ✓ 4 grid RFEA
- ✓ 2 keV ion energy range (DC bias)
- ✓ Apply up to 900 V pk-pk RF bias
- ✓ RF frequencies 100 kHz to 80 MHz
- ✓ Available in anodized aluminum, bare aluminum and stainless steel
- ✓ Easily replaceable button probes
- ✓ Operates from high vacuum to 300 mTorr; Up to 2 Torr with high pressure buttons

Button Sensors Available

- ✓ Low density 0.001 to 3 A/m^2
- ✓ Standard 0.01 to 50 A/m^2
- ✓ High density 0.1 to 700 A/m^2
- ✓ Pre-coated QCMs for etch rates

Benefits over QCM alone:

- ✓ Uses a second crystal to correct for temperature effects expanding the operating temperature range.
- ✓ The QCM can operate with an RF Bias
- ✓ Ion/Neutral deposition rates can be measured directly
- ✓ The Ion/Neutral ratio is a key parameter for thin film properties. Keeping this ratio constant between two different chambers will help match the film results, even with chambers of different sizes

NEW: High Pressure Buttons

- ✓ High Pressure Button extends measurement range to 2 Torr
- ✓ Note: Limited to 150 eV scanning range at max pressure in Argon

Key Features

Various Holder Designs

Holders of different shapes and sizes available on request

Compatible with majority of Biasing Conditions

Suitable for Grounded, Floating, DC biased and RF Biased conditions

Material Finishes

Sensor elements and holders available in anodized aluminium, bare aluminium or stainless steel

Replacable Sensor Elements

Can change the sensor elements to adjust sensitivity for different plasma densities

Portable for use in many chambers

Standard vacuum flanges available, different holder form factors for any substrate shape

Accurate and direct ion energy measurements

Calibrated measurement circuit using high-resolution power supplies for direct matching of ion energies chamber-to-chamber

Data for industry and R&D

Provides data for plasma-substrate interaction for tool characterization and to quickly identify process issues

Advanced software

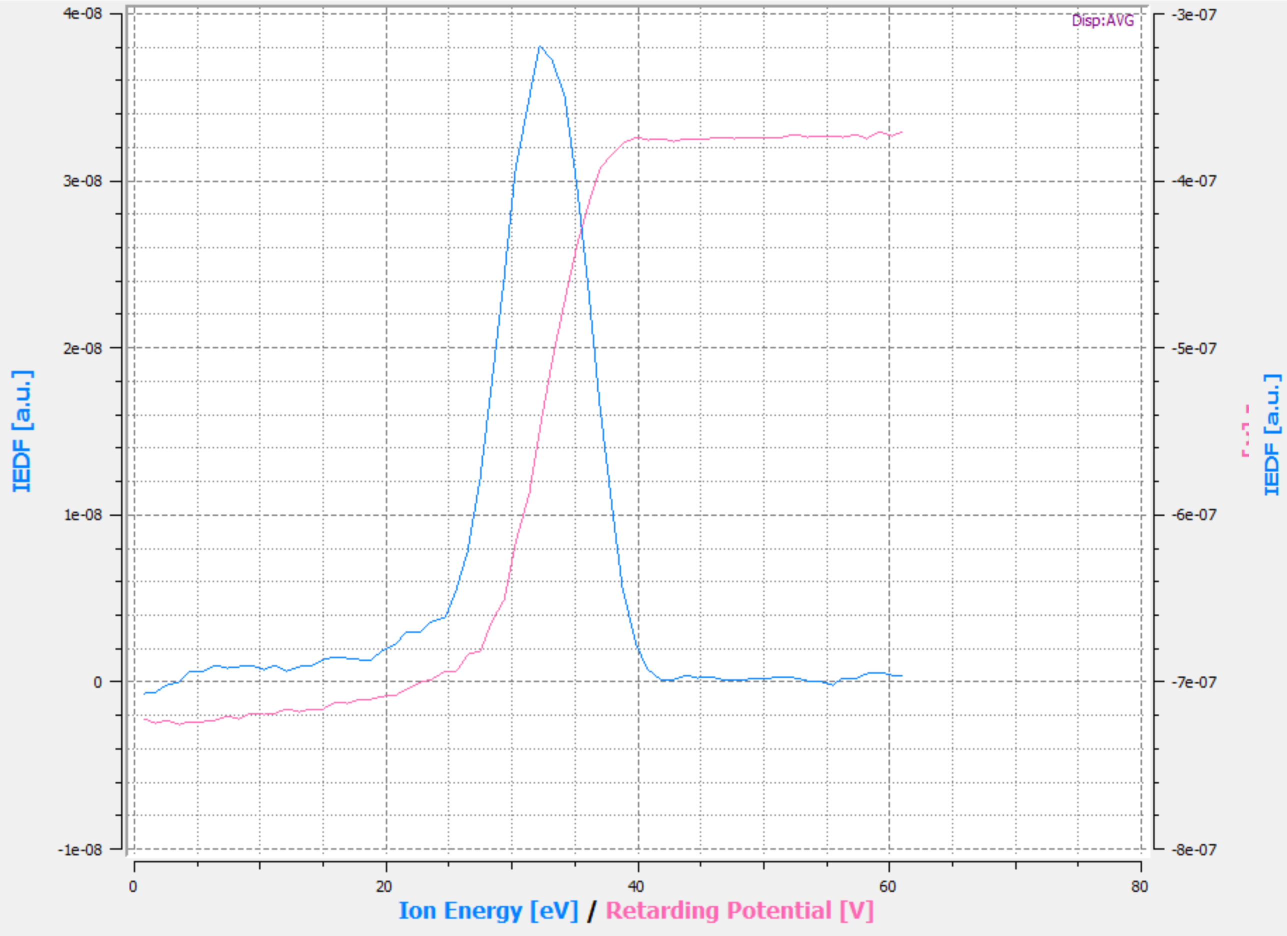
Fully automated software analysis of the IEDF and automatic DC bias potential measurement.

Technical Specifications

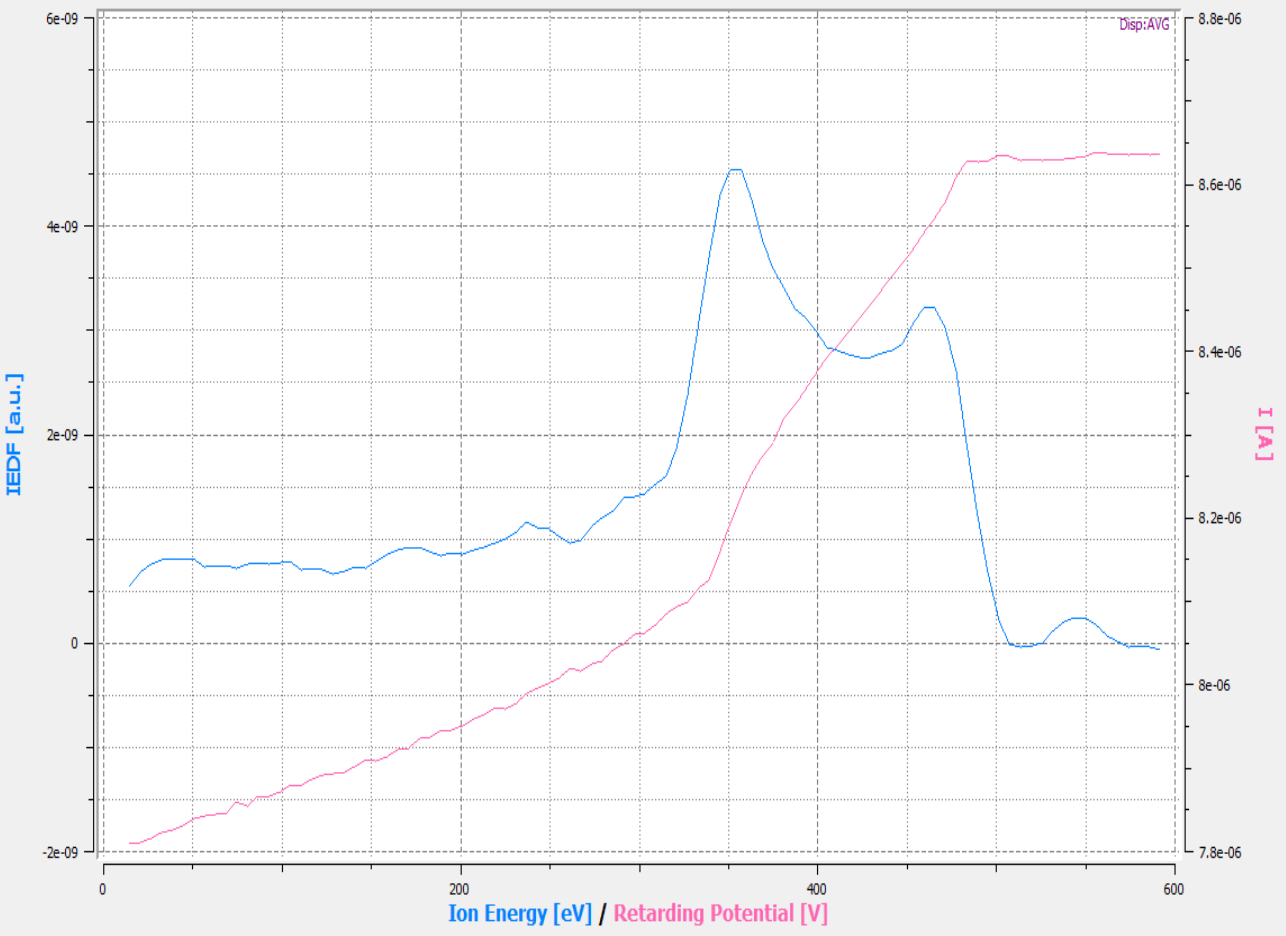
Parameters Measured	Range
Ion Energy Range	0 to 1500 eV (Standard/Low/High Density Buttons) 0 to 150 eV (High Pressure Button)
Ion Flux	0.001 to 700 A/m^2 (Dependent upon button)
Pressure Range	$\leq$ 300 mTorr (Standard/Low/High Density buttons) $\leq$ 2 Torr (High Pressure Button)
IEDF Resolution	±1 eV nominal
Max RF Bias voltage (applied to probe)	900 V (peak to peak)
Max DC Bias Voltage	-1940 V
Bias Frequency Range	100 kHz to 80 MHz
Quartz Crystal Frequency	3.5 MHz to 6.1 MHz with 1 Hz resolution
Mass Resolution at Crystal	12.3 ng/cm^3

- ✓ For more detailed specifications and different models available, visit https://www.impedans.com/quantum_sensors
- ✓ To see if the RFEA is suitable for your plasma application, see the applications list at https://impedans.com/rfea-pdf
- ✓ To arrange a technical discussion, contact support@impedans.com

Example Data: IV curves and IEDF Curves

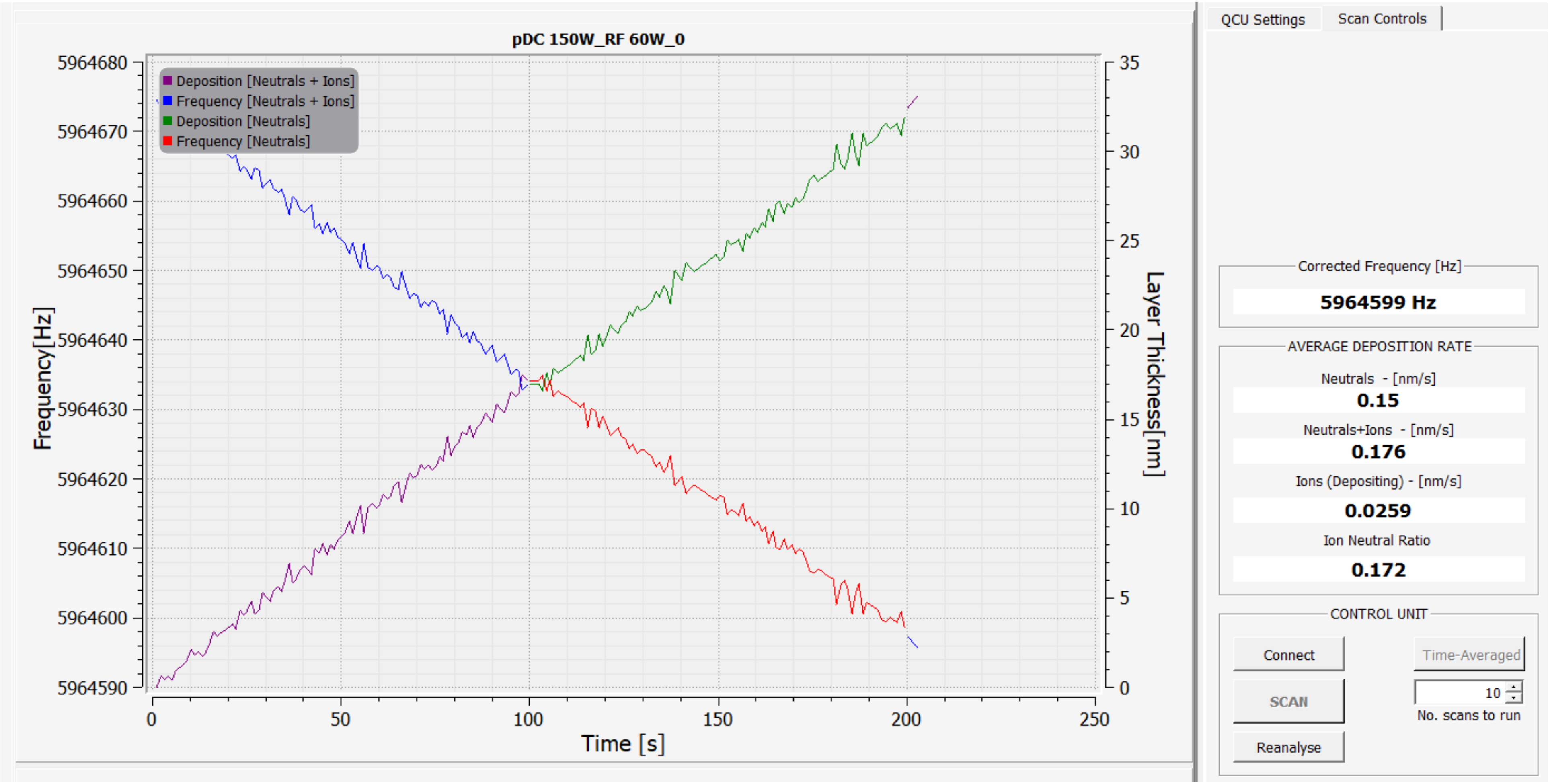


Grounded IEDF



RF Biased IEDF

Example Data: Deposition Rate Data



Corrected Frequency [Hz]: **5964599 Hz**

AVERAGE DEPOSITION RATE

Neutrals - [nm/s]: **0.15**

Neutrals+Ions - [nm/s]: **0.176**

Ions (Depositing) - [nm/s]: **0.0259**

Ion Neutral Ratio: **0.172**

CONTROL UNIT

No. scans to run: 10

Deposition Rate Data for Neutrals alone and for Ions + Neutrals together.

Ions in this example are depositing, increasing the total deposition rate

Applications

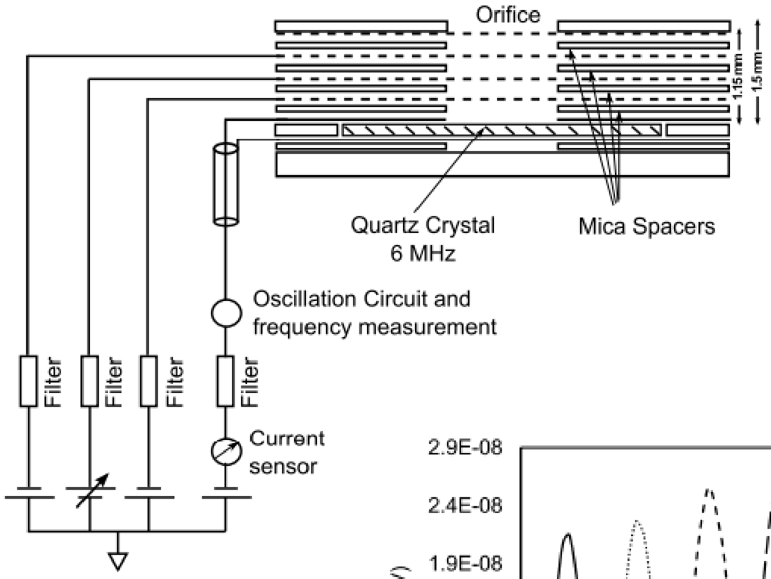
New design of compact retarding field analyser with integrated quartz crystal microbalance: Impedans Ltd.

Measurement of deposition rate and ion energy distribution in a pulsed dc magnetron sputtering system using a retarding field analyzer with embedded quartz crystal microbalance

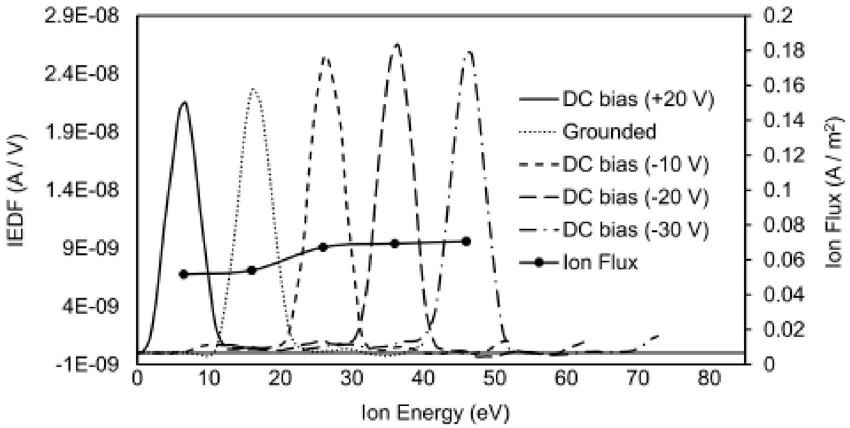
Saileshe Sharma et al, Dublin City University, Glasnevin, Dublin , Ireland
Impedans Limited, Chase House, City Junction Business Park, Northern Cross, Ireland

DOI: https://doi.org/10.1063/1.4946788

In this research work, the IEDF and Cu deposition rates are studied in an asymmetric bipolar p-dc sputtering system using the Quantum RFEA-QCM design. The effect of ion energy, substrate rf biasing, discharge power, and pressure on the deposition rate are also examined.

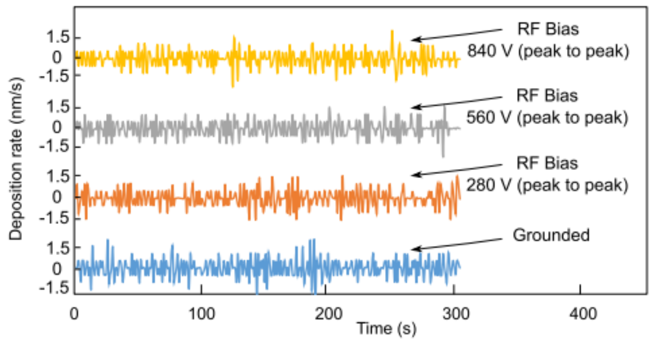


Schematic of QCM embedded Quantum RFEA design

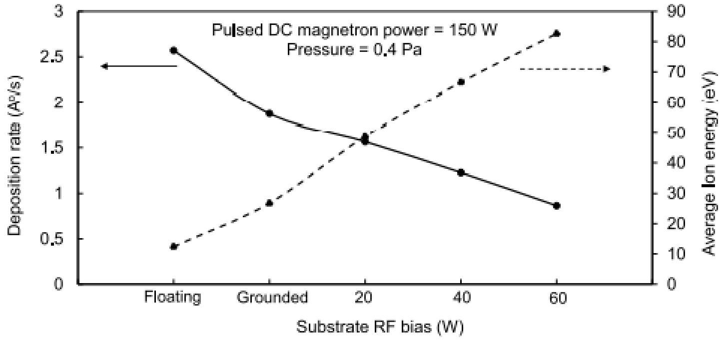


IEDF and ion flux at different substrate dc biasing

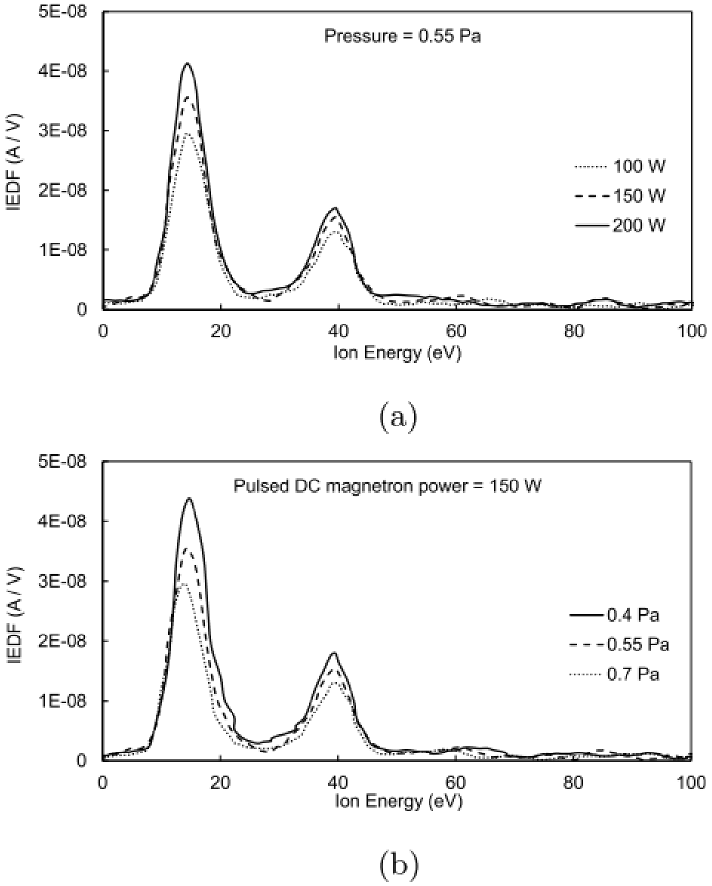
New design of compact retarding field analyser with integrated quartz crystal microbalance



Deposition rate vs time at different substrate rf biasing



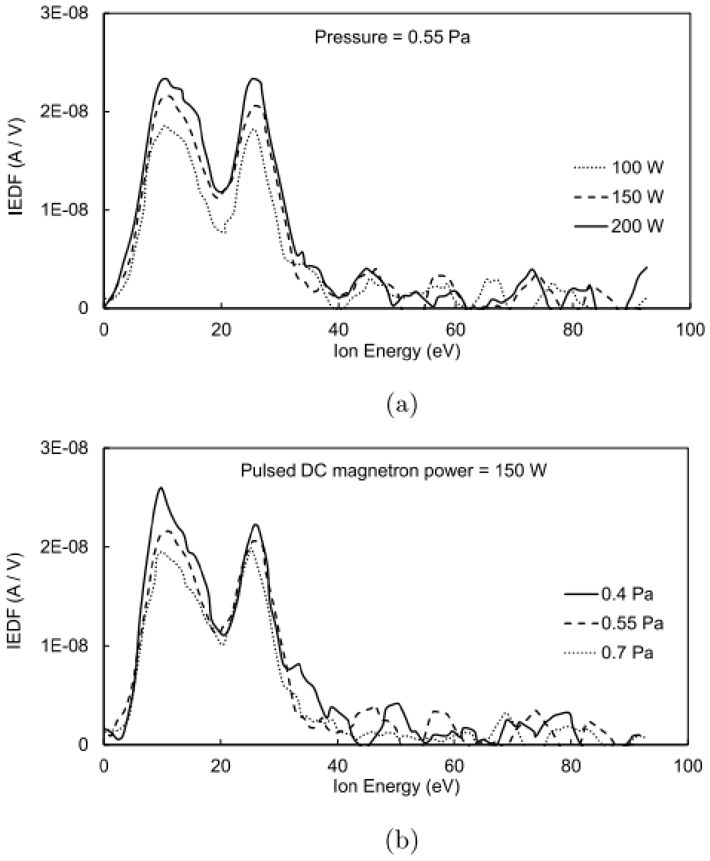
Deposition rate and average ion energy vs different substrate biasing.



(a)

(b)

IEDF on a grounded substrate at a fixed (a) pressure and (b) power.

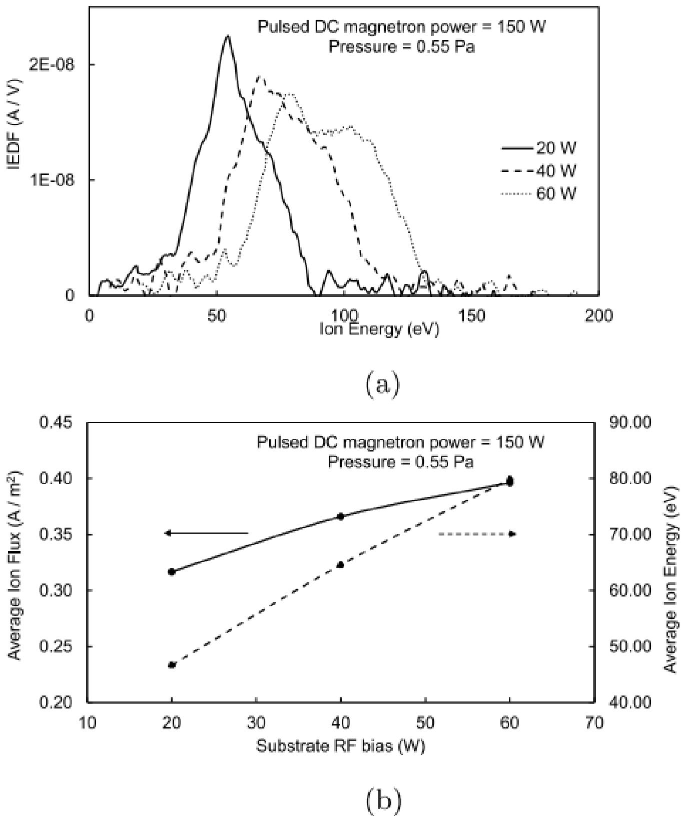


(a)

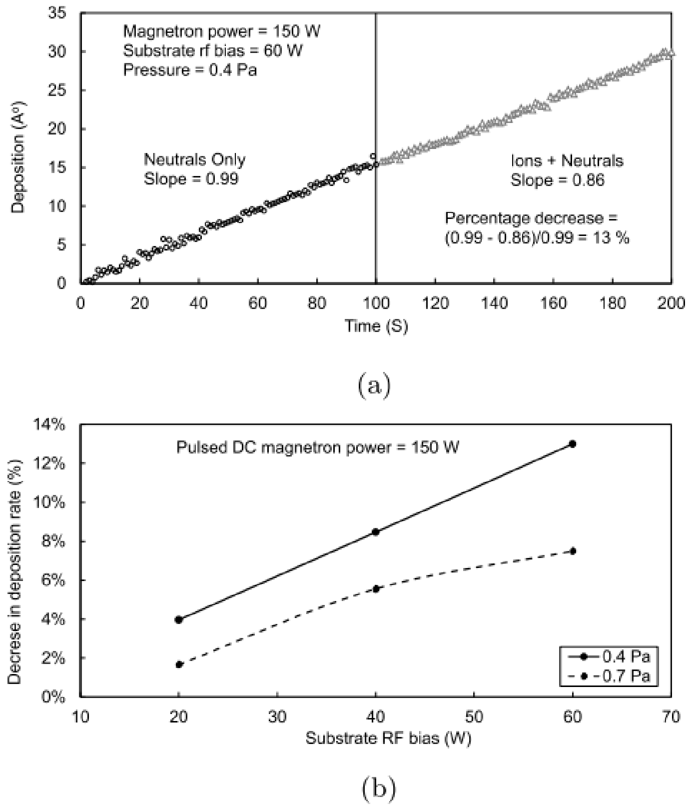
(b)

IEDF on a floating substrate at a fixed (a) pressure and (b) power

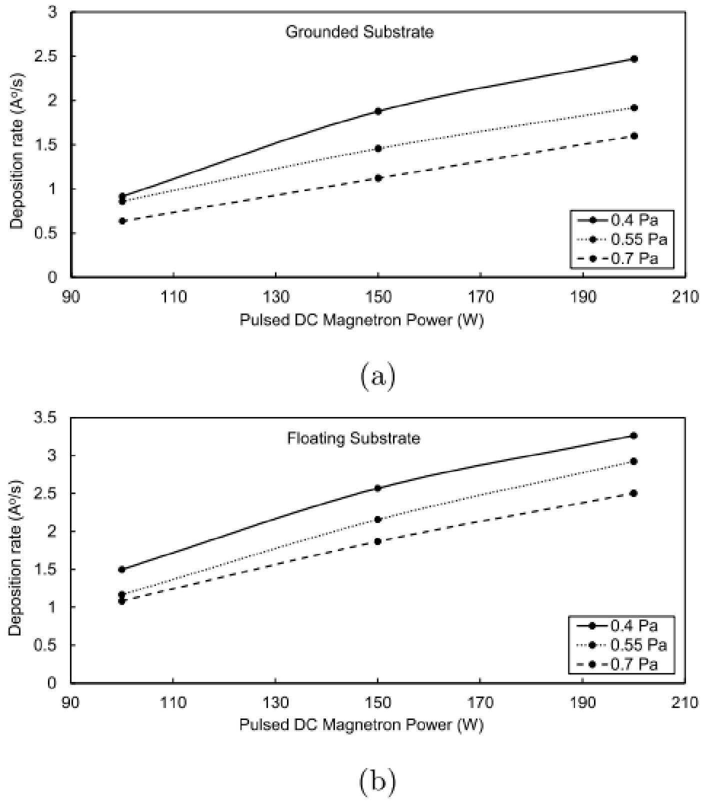
New design of compact retarding field analyser with integrated quartz crystal microbalance



(a) IEDF on a substrate biased at three different rf powers (20 W, 40 W, and 60 W). (b) Average ion flux and average ion energy vs RF bias.



(a) Deposition vs time graph to determine percentage decrease. (b) Percentage decrease in the deposition rate after ions are turned on.



Deposition rate vs p-dc power at different pressures on a (a) grounded substrate and (b) floating substrate

Measurement of the deposition rates in an ALD Plasma

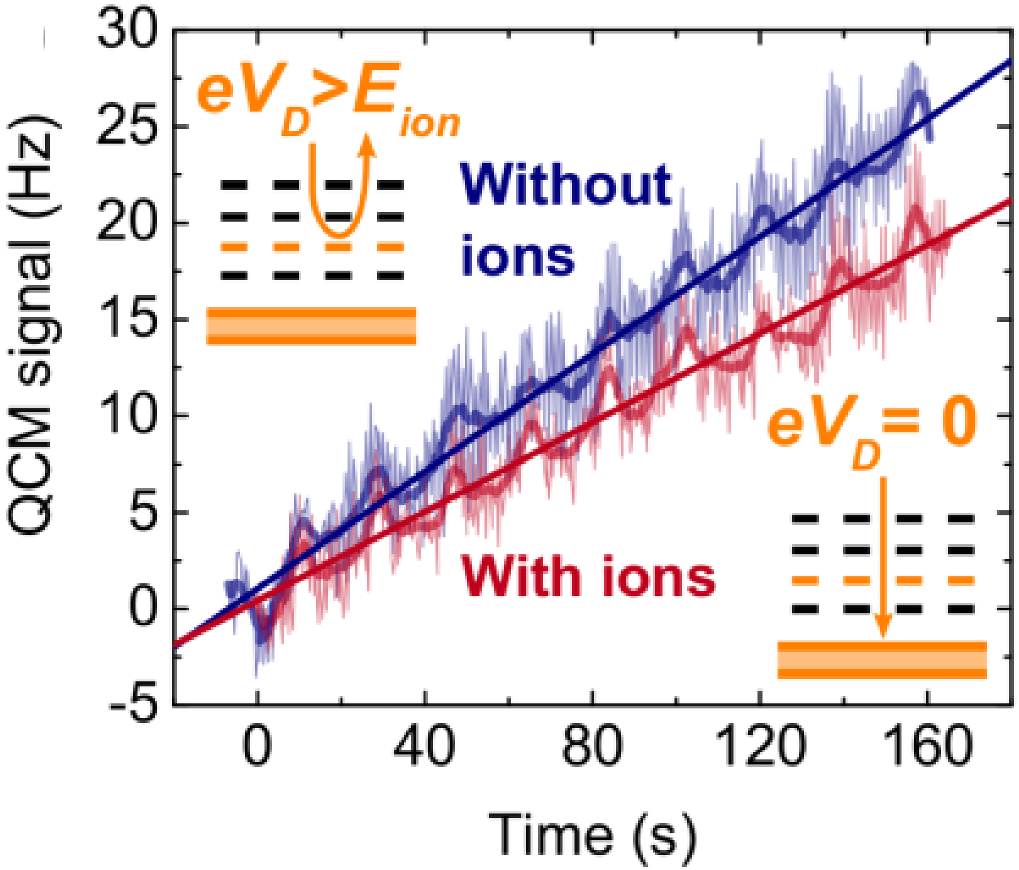
Evidence for low-energy ions influencing plasma-assisted atomic layer deposition of SiO2: Impact on the growth per cycle and wet etch rate

DOI: [10.1063/5.0015379](https://doi.org/10.1063/5.0015379)

The Quantum sensor was used in this paper to measure the Deposition rate with and without ions in an Atomic Layer Deposition (ALD) SiO_2 plasma process

Some example data is shown to the right

https://impedans.com/quantum-system-application-note-qc03



Example of the change in the QCM with and without the effect of ions in an ALD Plasma

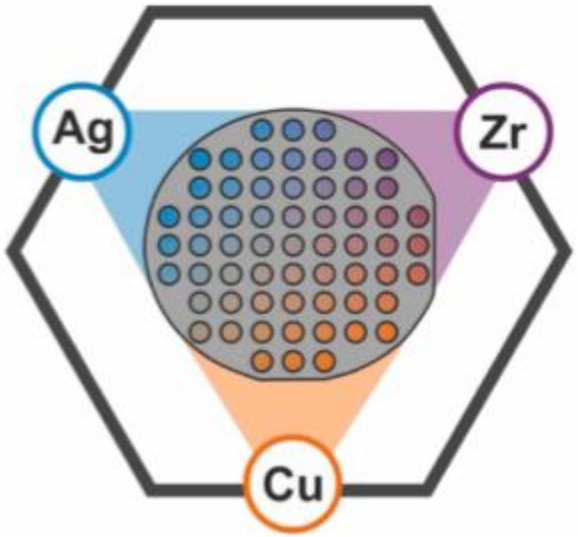
High power impulse magnetron sputtering (HiPIMS) of copper, silver and zirconium: influence of different pulse widths (25, 50 and 100 µs)

Influence of HiPIMS pulse widths on the deposition behaviour and properties of CuAgZr compositionally graded films

L. Lapeyre et al, Bern University of Applied Sciences, Institute for Applied Laser, Photonics and Surface Technologies ALPS, Quellgasse, Switzerland
Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Mechanics of Materials and Nanostructures, Switzerland
Tofwerk AG, Schorenstrasse, Switzerland

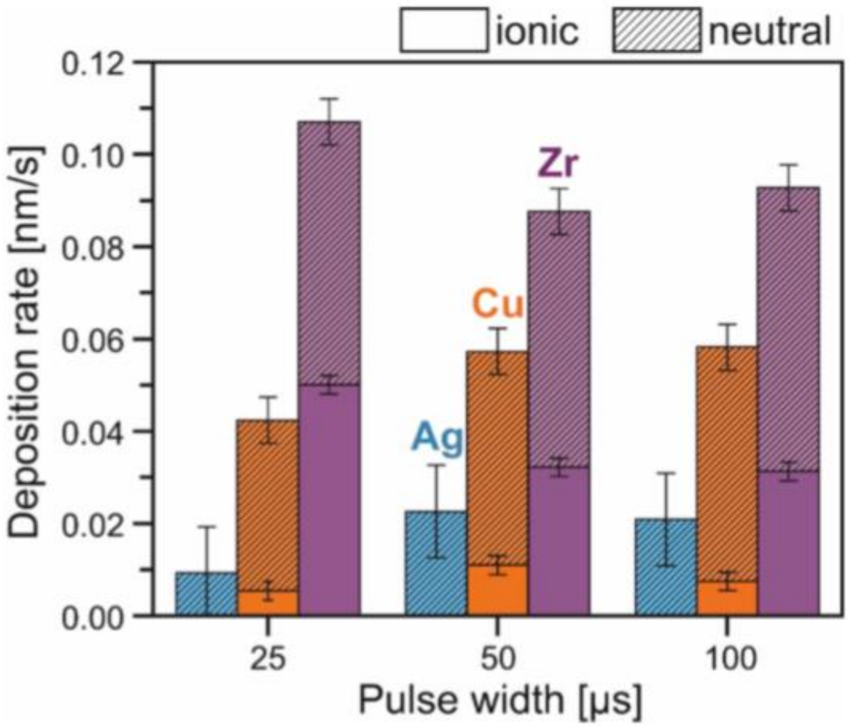
DOI: https://doi.org/10.1016/j.surfcoat.2022.129002

In this work, Three HiPIMS pulse widths were utilised to produce CuAgZr libraries. In situ plasma diagnostics identified the influence of pulse width, on each target. The microstructures of CuAgZr coatings were linked to the deposition conditions. Ionised flux fraction measurements were performed using a ⌀ 100 mm Quantum™ System m-QCM probe (Impedans Ltd., Ireland), to determine the mass deposition rate of neutral species and the total (neutral +ions) mass deposition rate.

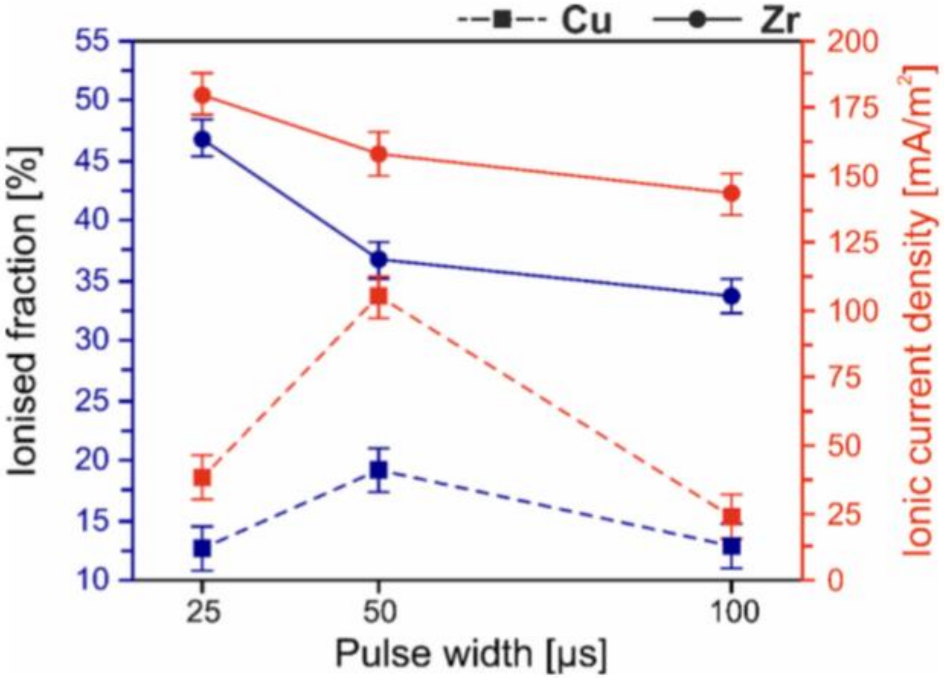


Schematic of plasma source placement vs substrate and mask position

High power impulse magnetron sputtering (HiPIMS) of copper, silver and zirconium: influence of different pulse widths (25, 50 and 100 µs)



Ag, Cu and Zr deposition rates, with distribution of neutral and ionic species, for 25, 50 and 100 µs pulse widths (detailed values given in supplementary information)



Ionized fraction and ionic current density for Cu and Zr, with no ionic signal measured during Ag discharges.

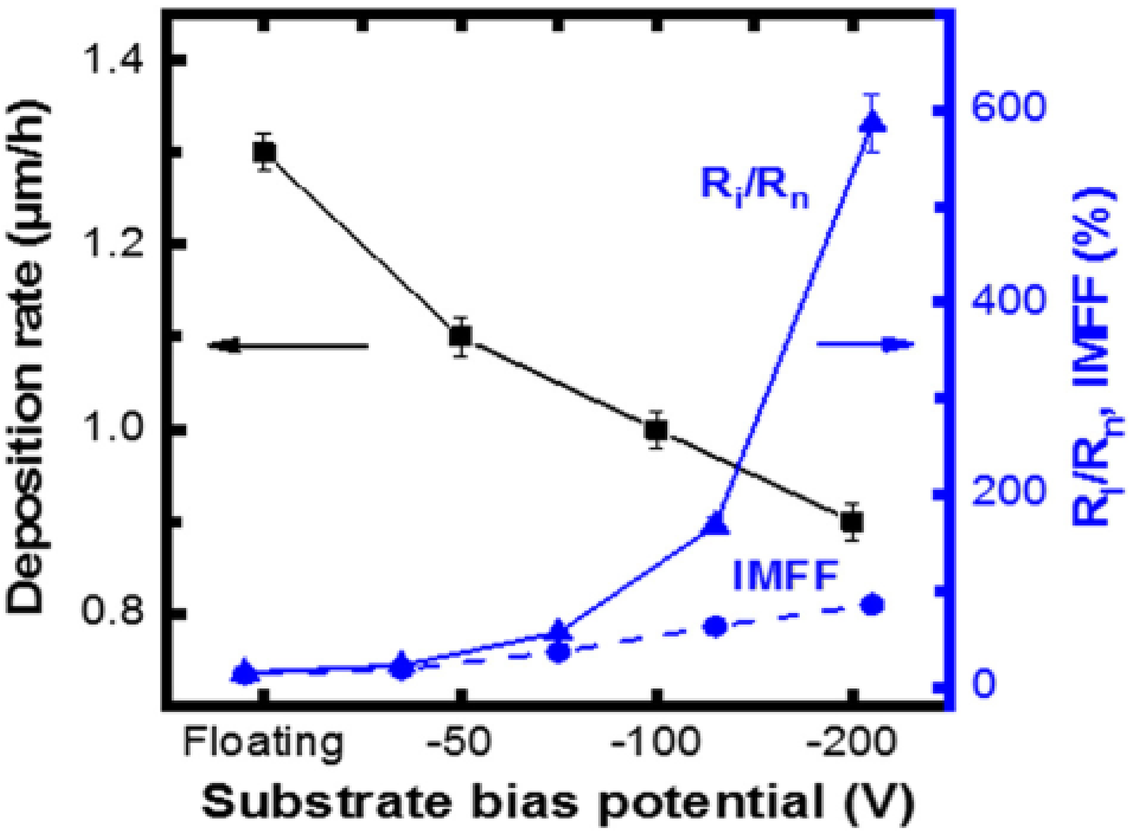
Measurement of the deposition rates and Ion/Neutral fraction in a HiPIMS discharge

Effects of HiPIMS discharges and annealing on Cr-Al-C thin films

DOI: [10.1016/j.surfcoat.2020.126141](https://doi.org/10.1016/j.surfcoat.2020.126141)

The Quantum sensor was used in this paper to measure the Deposition rates and the Ion/Neutral ratio as a function of the substrate bias potential (ion energy).

Some example data is shown to the right



Effect of the Substrate bias potential on the Deposition Rate and the Ion/Neutral ratio

Theory

RFEA Structure

All grids are made of nickel with a 20 x 20 μm square apertures

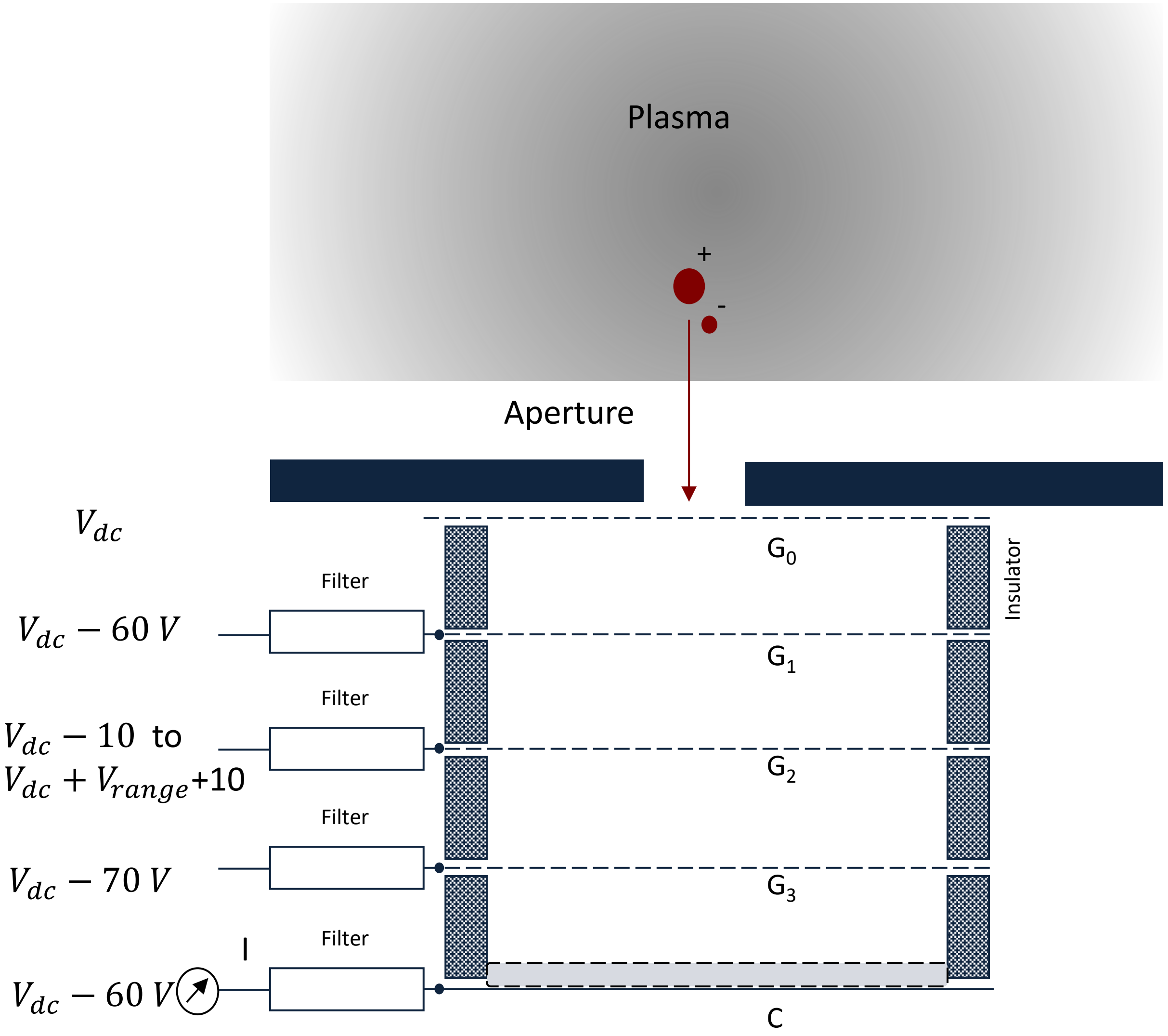
G_0 is designed to reduce the diameter of the sampling orifice to less than the Debye length in order to prevent plasma formation within the RFEA. The grid, which is connected to the body of the sensor (and therefore the electrode), will be biased (V_{dc}) according to the condition of the electrode (Grounded, Floating, RF Biased).

G_1 acts a an electron repulsion grid. This is designed to repel electrons from the plasma that enter into the sensor as they can distort the IED being measured.

G_2 acts as the discriminator of the ions based on their energy. As the voltage is swept from V_{dc} to $V_{dc} + V_{range}$ fewer ions are able to pass through the electric potential causing the current to change.

G_3 acts as a secondary electron suppression grid. It is negatively biased with respect to the collector ($C - 10\ V$ typically) to create a retarding potential for secondary electrons that can be emitted from the surface of the collector due to energetic ion impact.

C is the Quartz Crystal Microbalance and the collector electrode to which a negative bias is applied to attract the ions for detection.



RFEA Equations

Ion Energy Distribution Function (IEDF) Calculation:

$$f(x_i) = \frac{y_i - y_{i-1}}{x_i - x_{i-1}} \qquad \mathrm{n} = 1$$

$$f(x_i) = \frac{\sum_{j=1}^{n} y_{i+j} - \sum_{j=1}^{n} y_{i-j}}{\sum_{j=1}^{n} x_{i+j} - \sum_{j=1}^{n} x_{i-j}} \qquad n \geq 2 \qquad (1)$$

x and y representing the voltage and current values respectively

Ion Flux:

$$J_i = \frac{0.5\, f(x_i)}{Area \,*\, Transmission} \qquad (2)$$

Average Energy:

$$E_i = \frac{\int_{E_{min}}^{E_{max}} E\, f(E) dE}{\int_{E_{min}}^{E_{max}} f(E) dE} \qquad (3)$$

Sheath Width:

$$\bar{s} = \frac{2}{3}\left(\frac{2e}{M_i}\right)^{\frac{1}{4}}\left(\frac{\varepsilon_0}{\bar{J_i}}\right)^{\frac{1}{2}}\bar{V_s}^{\frac{3}{4}} \qquad (4)$$

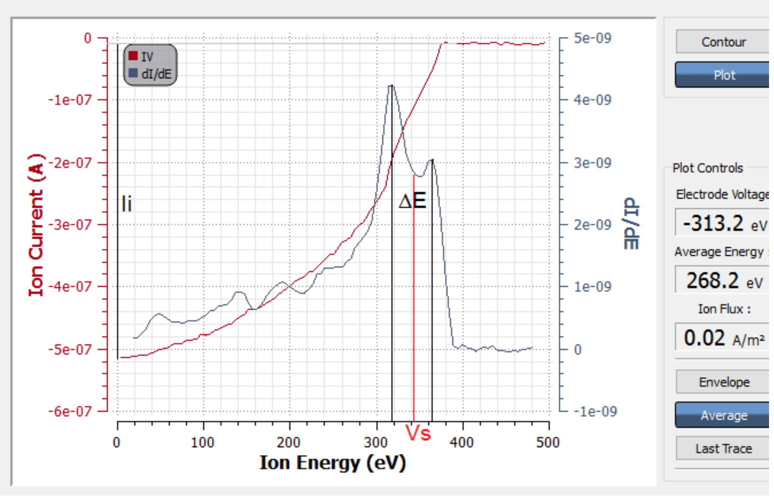
$\bar{V_s}$ is the DC sheath voltage

Ion Transit Time:

$$\tau_i = 3\,\bar{s}\sqrt{\frac{M}{2\,e\,\hat{V_s}}} \qquad (5)$$

Peak Separation:

$$\Delta E = \frac{2eV_{pp}}{\pi}\left(\frac{\tau_{RF}}{\tau_i}\right) \qquad (6)$$



Electrode Voltage -313.2 eV

Average Energy 268.2 eV

Ion Flux : 0.02 A/m²

Quartz Crystal Microbalance Equations

Sauerbrey Equation

$$\Delta f = -\frac{2f_0}{A\sqrt{\rho_q \mu_q}}\Delta m = -C_f\,\Delta m \qquad (7)$$

Where f_0 is the resonant frequency (Hz), A s the active crystal area, ρ_q is the density of quartz (g/cm^3), μ_q is the shear modulus of the quartz ($g\ cm^{-1}\ s^{-2}$) and C_f is just the combination of constants

Material Thickness:

$$T_f = \frac{\Delta m}{\rho_f} = -\frac{\Delta f}{C_f\ \rho_f} \qquad (8)$$

Where ρ_f is the density of the deposited material

Z-Match method:

$$\frac{\Delta m}{A} = \frac{N_q \rho_q}{\pi\ Z\ f_L}\tan^{-1}\left[Z\tan\left(\frac{\pi(f_v - f_L)}{f_v}\right)\right] \qquad (9)$$

Where f_L and f_v are the frequency of the loaded and unloaded (i.e. resonant) crystals (Hz) respectively, N_q is frequency constant for AT-cut quartz crystal (Hz Å), Z is the ratio of acoustic impedance of the crystal to that of the deposited film.

Temperature Calibration:

$$f_N = f_{N,QCM1} - \left[f_{N,QCM2} - f_{0,QCM2}\right] \qquad (10)$$

Where f_N is the corrected frequency and $f_{0,QCM2}$ is the initial resonance frequency of the calibration crystal (i.e. before the temperature effects)

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