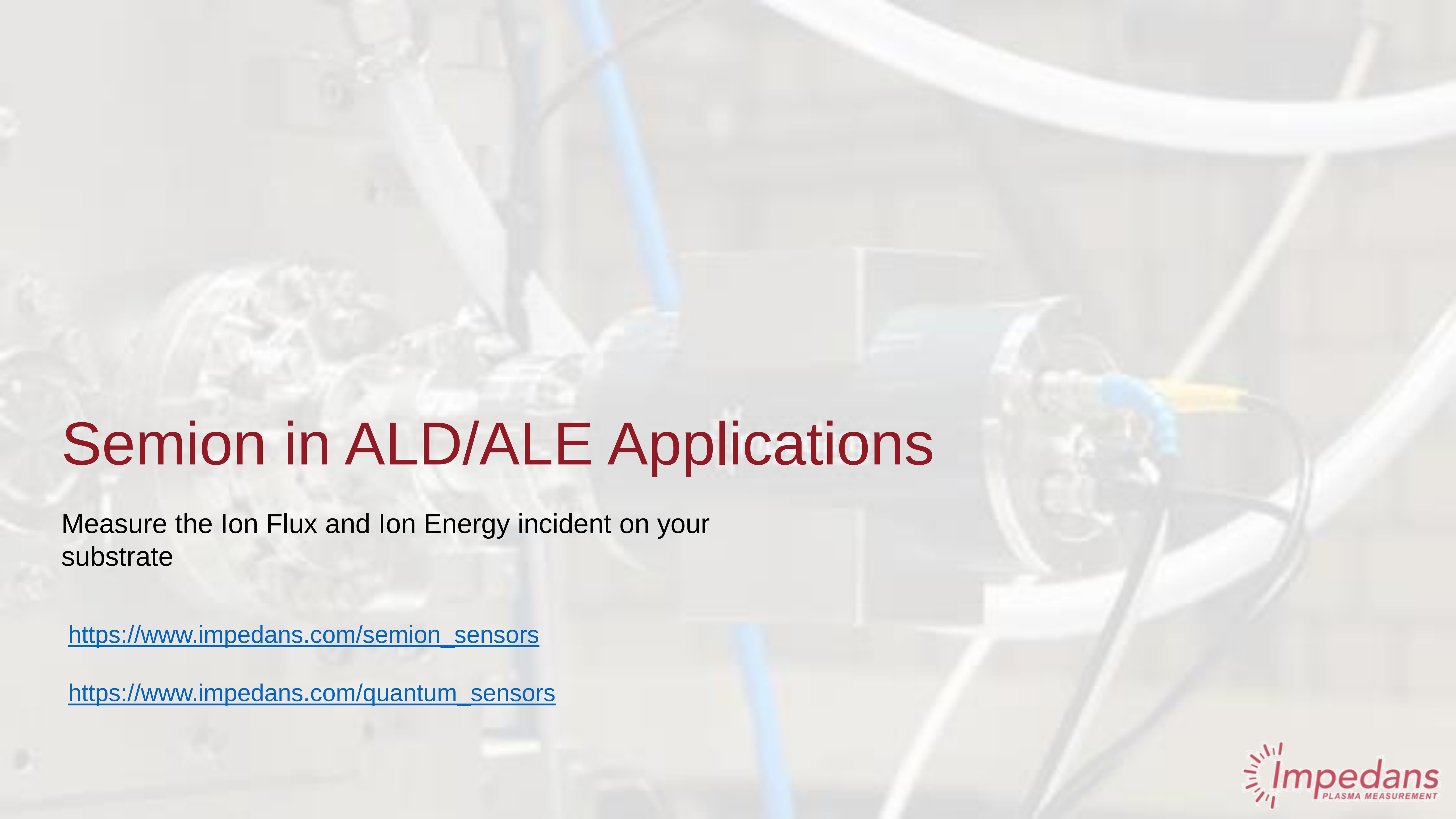


Semion in ALD/ALE Applications

Measure the Ion Flux and Ion Energy incident on your substrate

https://www.impedans.com/semion_sensors

https://www.impedans.com/quantum_sensors

ALD Applications

Influence of oxygen ions and photons during remote plasma atomic layer deposition of metal oxide thin films

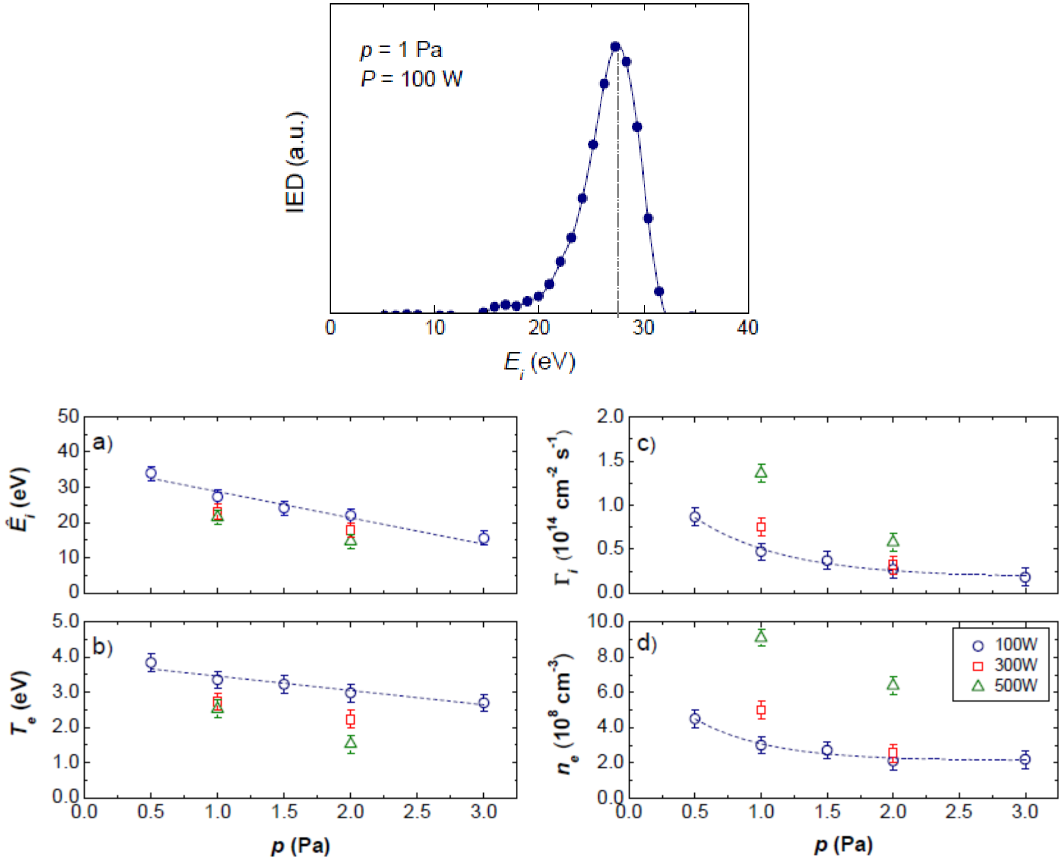
Oxford Instruments FlexAL

The Influence of Ions and Photons during Plasma-Assisted ALD of Metal Oxides

DOI: https://doi.org/10.1149/1.3485242

In this work, it is demonstrated that the ions and photons present in plasmas during plasma-assisted Atomic Layer Deposition (ALD) can influence the deposition process and the material quality significantly. The ion energy and flux were studied for several oxygen gas pressures and ICP powers.

Some example data is shown to the right



Example of RFEA measurements as measured for an O_2 plasma. Also shown the peak ion energy E_i , electron temperature T_e , Ion flux Γ_i and electron density n_e.

Control of the ion energy during plasma-assisted ALD using two substrate-biasing technique

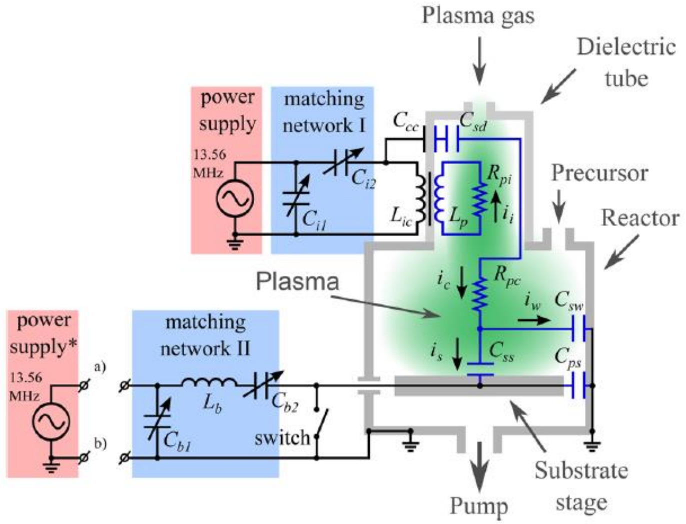
Substrate-biasing during plasma-assisted atomic layer deposition to tailor metal-oxide thin film growth

DOI: https://doi.org/10.1116/1.4756906

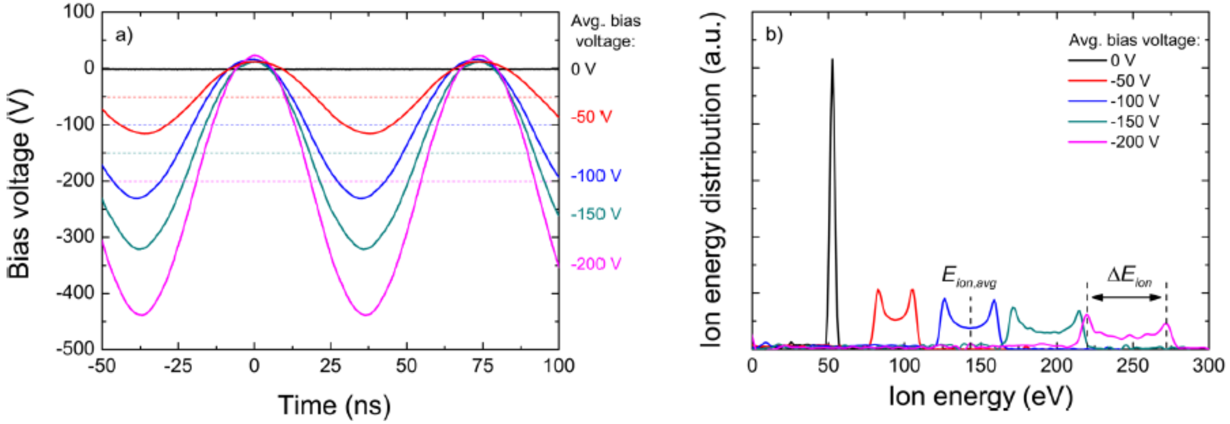
This article discusses the implementation of substrate-tuned biasing and radio frequency (RF) substrate biasing in a remote plasma ALD reactor. The impact of substrate biasing on the ion energy distribution (IED) is reported in detail.

Some example data is shown to the right

ICP for ALD



Remote plasma ALD reactor equipped with an inductively-coupled plasma source.



Substrate-tuned bias voltage, V_{subs} as a function of time, and the corresponding IEDs

Impact of impingement of ions with larger mass and higher energy on the chemical and microstructural properties of HfN_x films

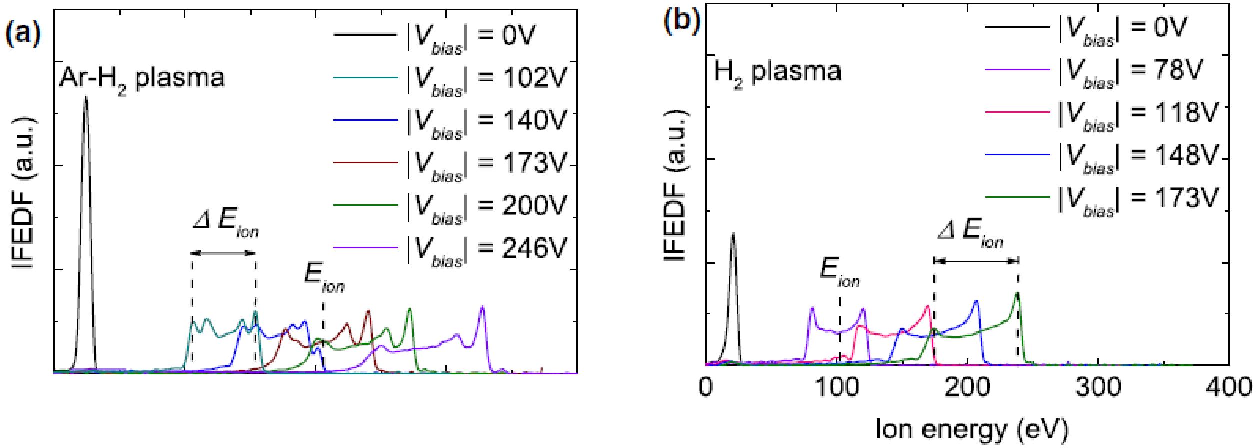
Plasma-Assisted ALD of Highly Conductive HfN_x: On the Effect of Energetic Ions on Film Microstructure

DOI:https://doi.org/10.1007/s11090-020-10079-x

In this work, the impact of impingement of ions with larger mass and higher energy on the chemical and microstructural properties of HfN_x films is addressed. The ion energy measurements carried out in the present work indicate that the growing HfN_x film is subjected to a higher average ion energy in the case of Ar–H_2 plasma with respect to the previously reported H_2 plasma process.

Some example data is shown to the right

Oxford Instruments FlexAL



Example of RFEA measurements in (a) Ar–H_2 plasma operated at 6 mTorr and (b) H_2 Plasma operated at 30 mTorr for various values of $|V_{bias}|$

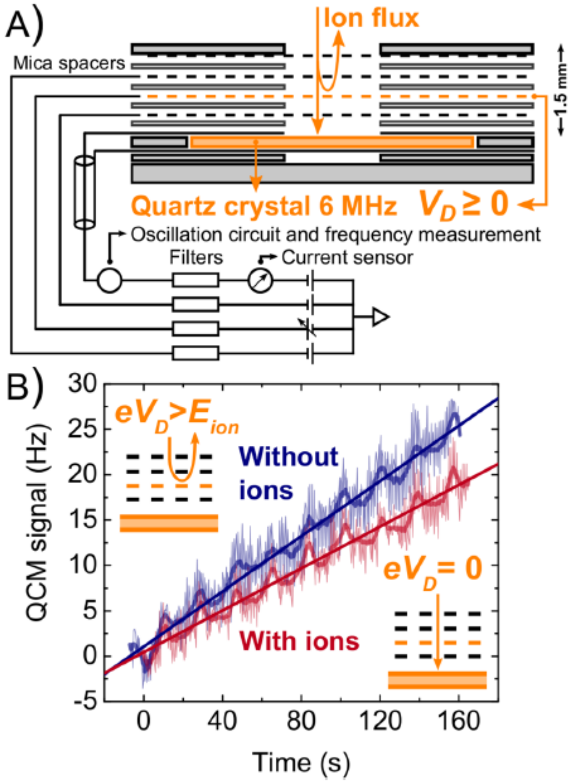
Control of the ion energy during plasma-assisted ALD using two substrate-biasing technique

Evidence for low-energy ions influencing plasma-assisted atomic layer deposition of SiO_2: Impact on the growth per cycle and wet etch rate

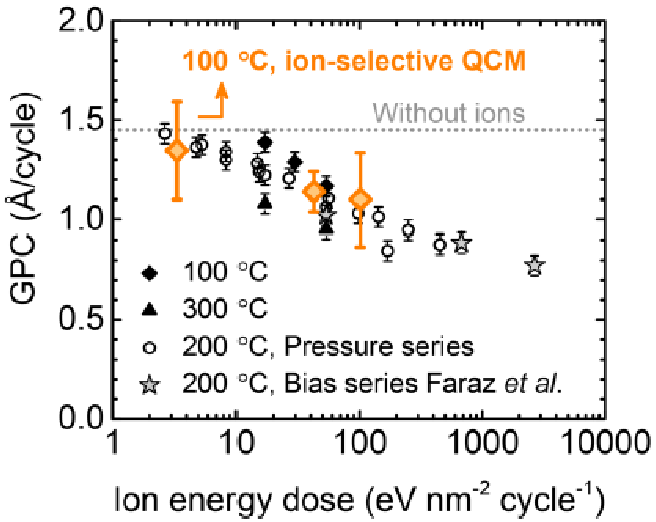
DOI: https://doi.org/10.1063/5.0015379

This work provides evidence that plasma-assisted atomic layer deposition (ALD) of SiO_2, a widely applied process and a cornerstone in self-aligned multiple patterning, is strongly influenced by ions even under mild plasma conditions with low-energy ions.

Some example data is shown to the right



Oxford Instruments FlexAL



(A) Cross-sectional side view of the ion-selective quartz crystal microbalance Sensor. (B) Results obtained for the plasma ALD of SiO_2. Also shown the growth per cycle (GPC) of SiO_2 grown with ion exposure with the supplied ion energy dose. $SiH_2(NEt_2)_2$ used as the precursor (with doses of 830 mTorr.s per cycle) and 100/50 sccm O_2/Ar plasma as the co-reactant. (600W ICP power at 13.56 MHz)

Understanding the operation of RFEAs for ALD/ALE research

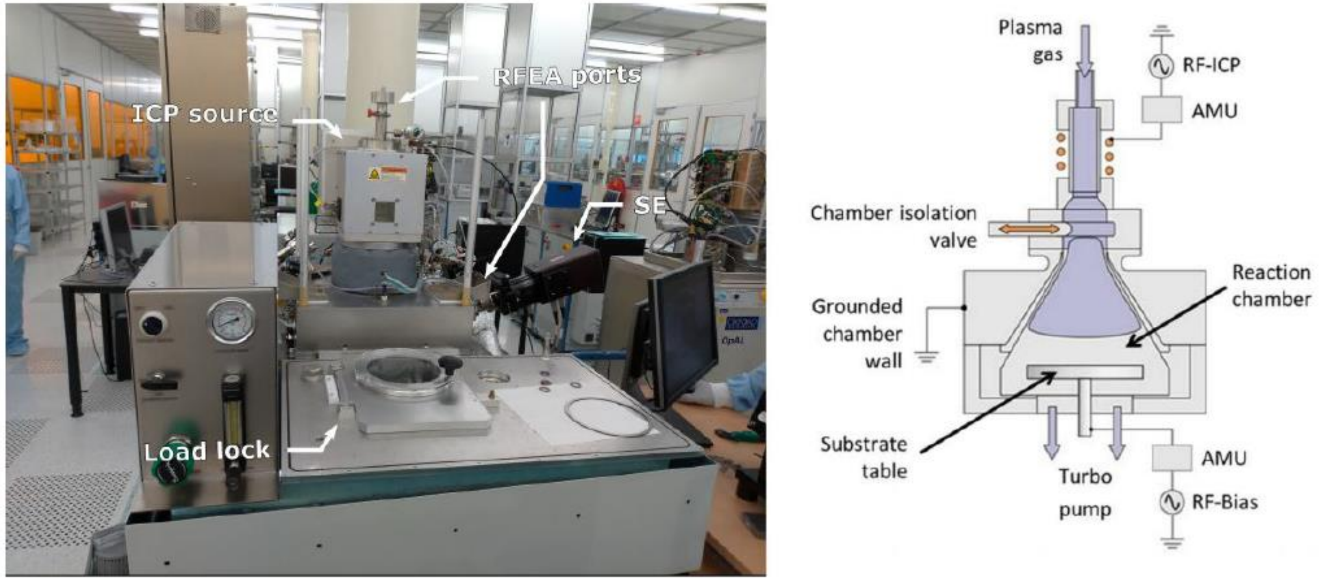
Functional analysis of retarding field energy analyzers for ion energy distribution measurements in plasma enhanced atomic layer deposition

DOI: https://research.tue.nl/en/studentTheses/functional-analysis-of-retarding-field-energy-analyzers-for-ion-e

This work aims to obtain an improved understanding of the principles of RFEA measurements. Both simulations and experimental methods are used to gain insight into the various aspects that govern the operation of an RFEA and the cause of measurement artifacts.

Some example data is shown to the right

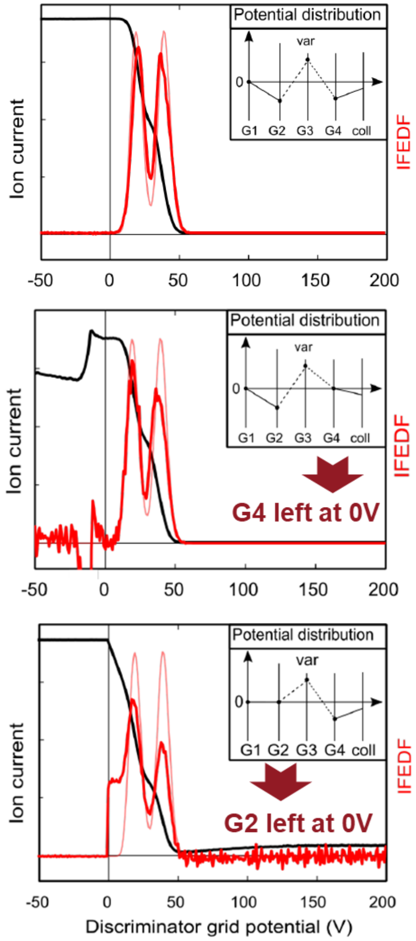
Oxford Instruments FlexAL



FlexAL2 reactor used for RFEA measurements

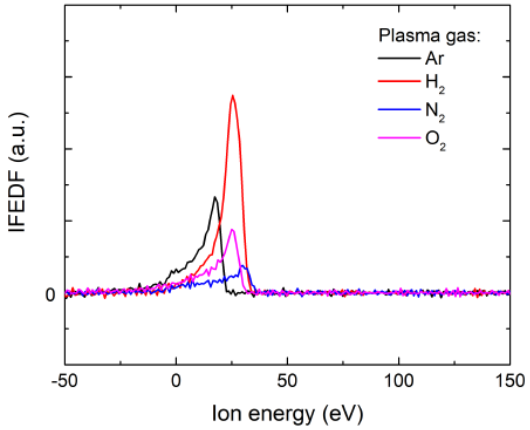
Understanding the operation of RFEAs for ALD/ALE research

Influence of grid potentials

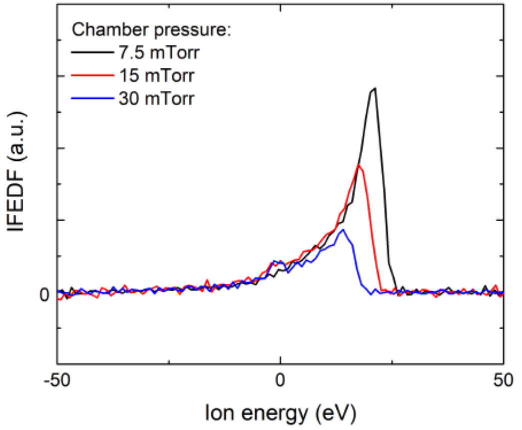


Simulated IV curve (black) and IED (dark red) of an RFEA measurement

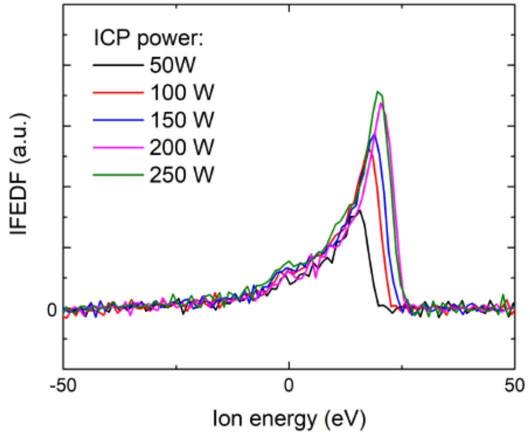
IFEDFs measured for various plasma conditions



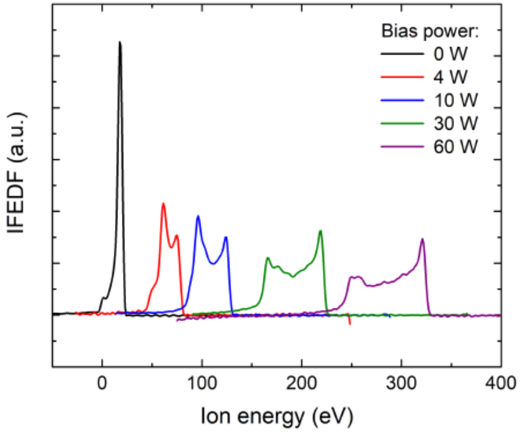
15 mTorr using 100W of ICP power



Argon plasma at three different pressures at 100W of ICP power



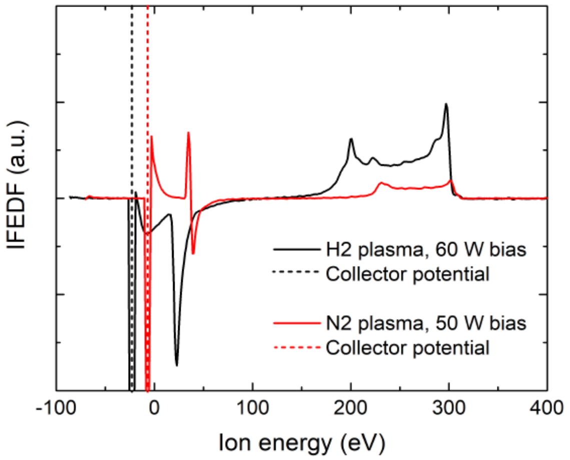
Argon plasma at 15 mTorr



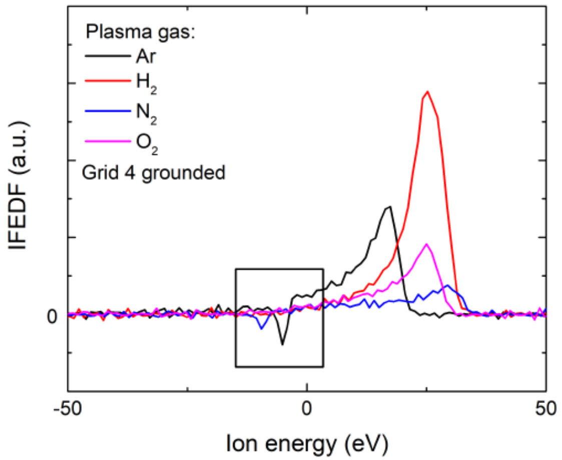
Effects of bias power on a 600W argon plasma at 9 mTorr

Understanding the operation of RFEAs for ALD/ALE research

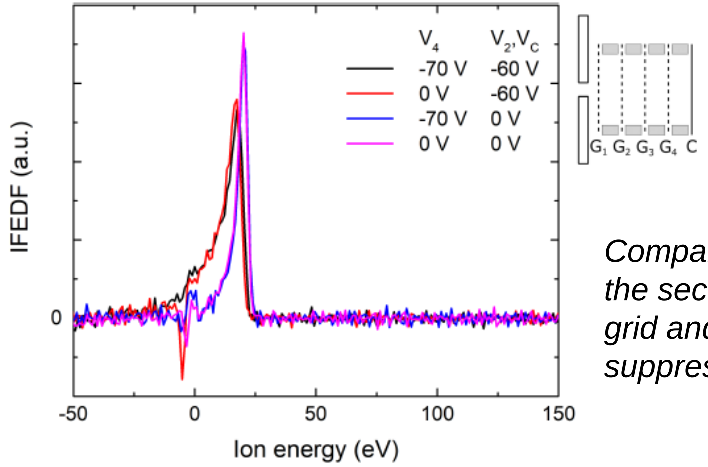
Investigating role of Secondary electrons



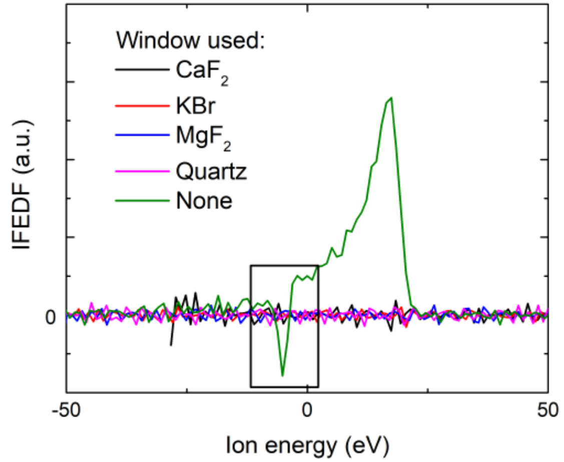
Examples of measurements performed in the FlexAL reactor that show a secondary electron peak.



Comparison of the effects of the disabled secondary electron suppression grid on the measured IFEDF between the four gases.



Comparison of the effect of grounding the secondary electron suppression grid and/or the plasma electron suppression grids.



Peaks in the IFEDF where no filter was used indicates that UV photons are not a source of secondary electrons.

Results of measurements of an argon plasma where a variety of filters were placed on the RFEA.*(100W argon plasma at 15 mTorr and a disabled secondary electron suppression grid).*

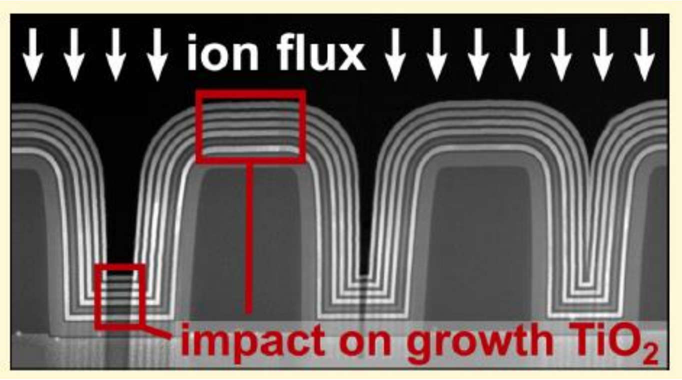
Comparison of TiO_2 film growth with and without Ion flux contribution during plasma-assisted atomic layer deposition process

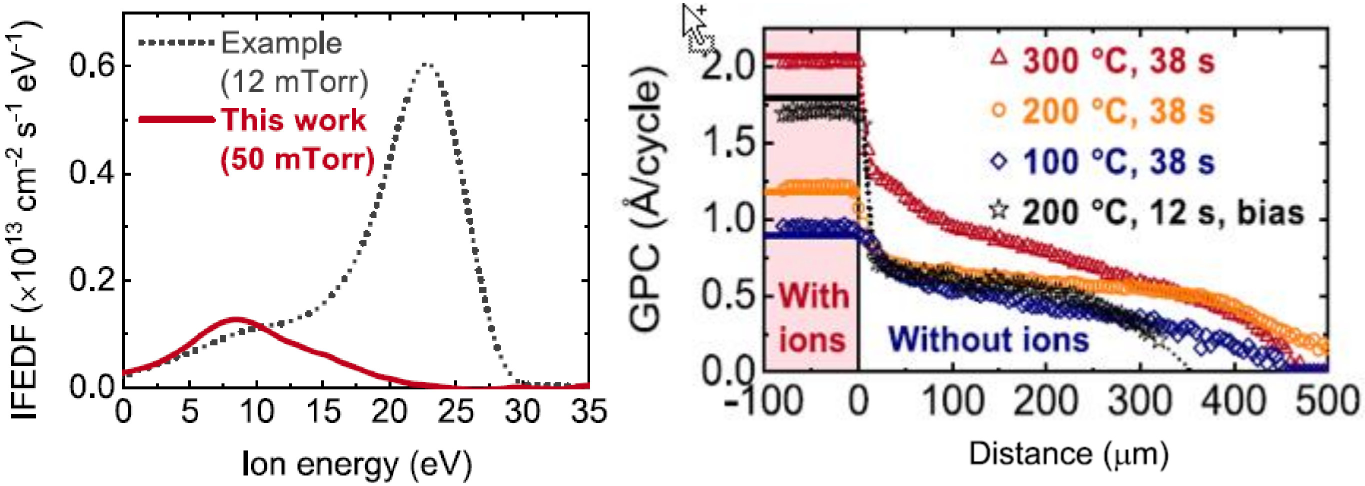
Impact of Ions on Film Conformality and Crystallinity during Plasma-Assisted Atomic Layer Deposition of TiO_2

DOI: https://doi.org/10.1021/acs.chemmater.1c00781

In this work, it is demonstrated that the ions, including ions with a low energy of <20 eV have a strong impact on the growth of TiO_2 thin films by plasma plasma-assisted Atomic Layer Deposition (ALD). Specifically, it is shown that the Growth Per Cycle (GPC) in terms of film thickness can increase by 20 to >200% under the influence of ions.

Some example data is shown to the right





Example of RFEA measurements as measured for O_2/Ar plasma. Also shown GPC of TiO_2 films grown using 400 cycles on LHAR cavity structures, indicating a significantly higher GPC in the region where the TiO_2 is grown with exposure to ions (left).

Characterisation of a new low-damage remote plasma ALD system (Atomfab) for high-volume manufacturing of Al_2O_3 for GaN devices

Innovative remote plasma source for atomic layer deposition for GaN devices

DOI: https://doi.org/10.1021/acs.chemmater.1c00781

This article outlines ion energy flux distribution functions and flux levels for a new remote plasma ALD system, Oxford Instruments Atomfab™, which includes an innovative, RF-driven, remote plasma source.
The source design is optimized for ALD for GaN high-electron-mobility transistors (HEMTs) for substrates up to 200mm.

Some example data is shown to the right

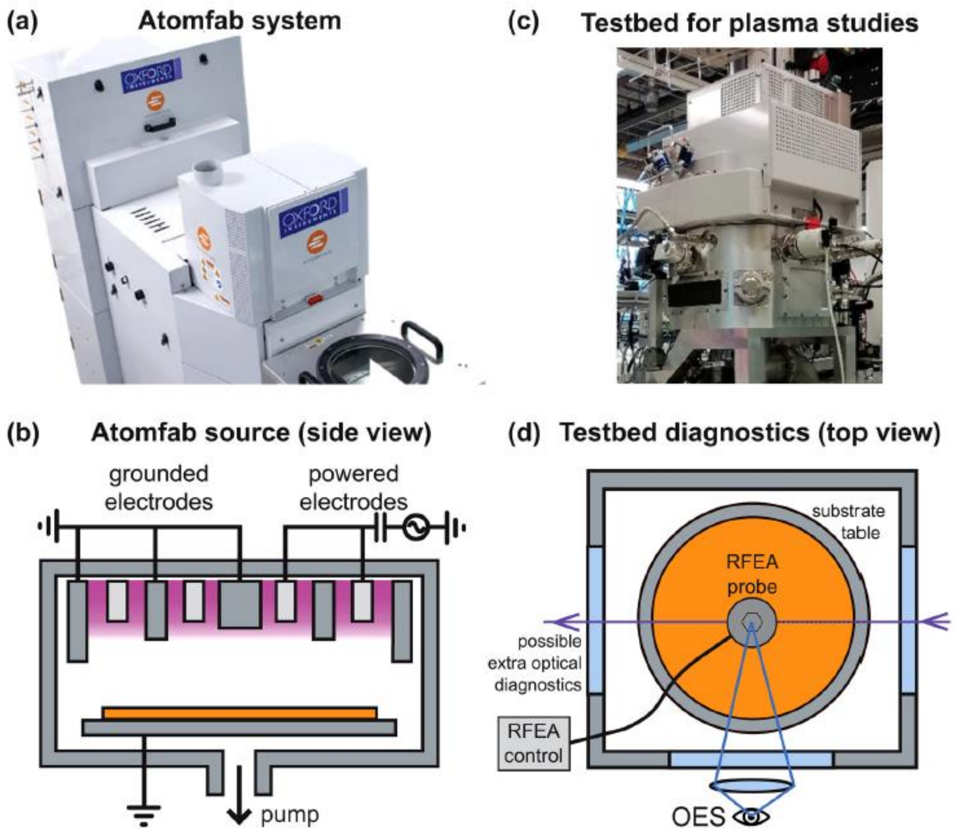
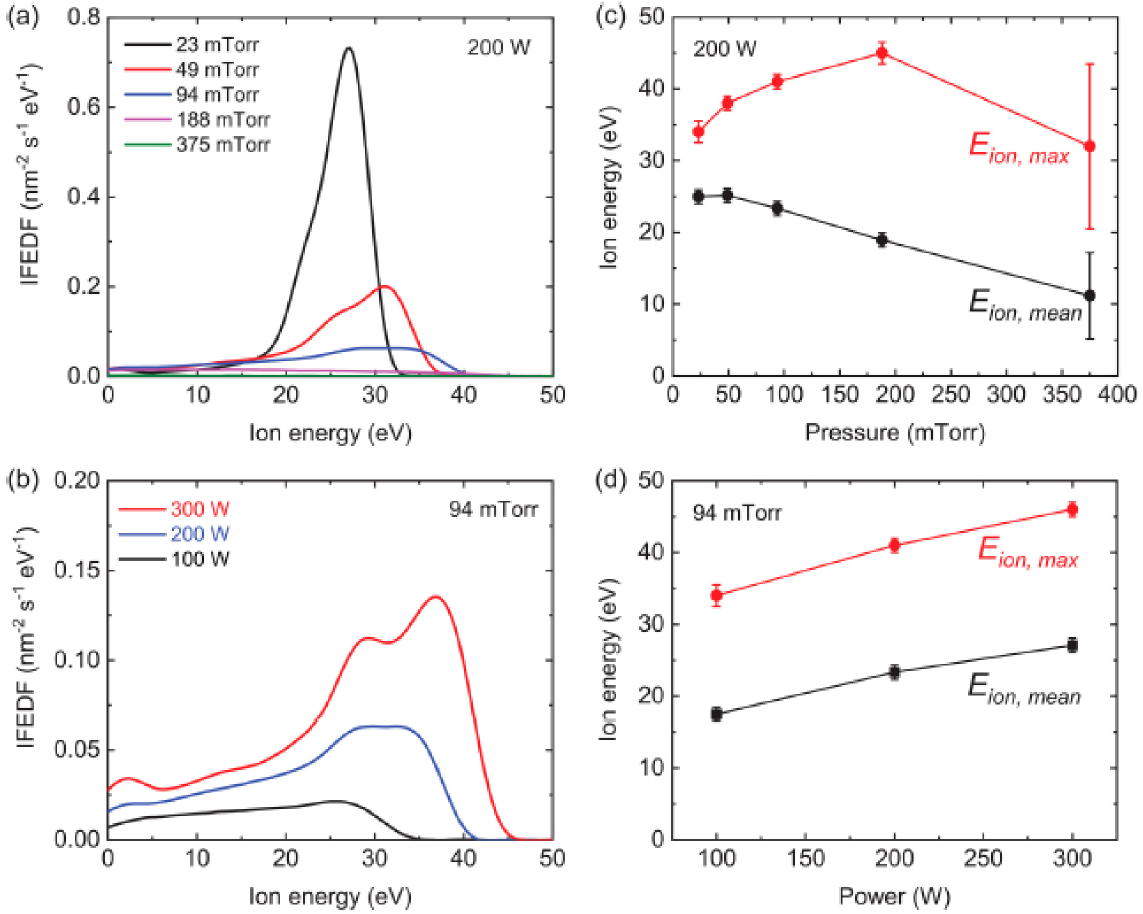
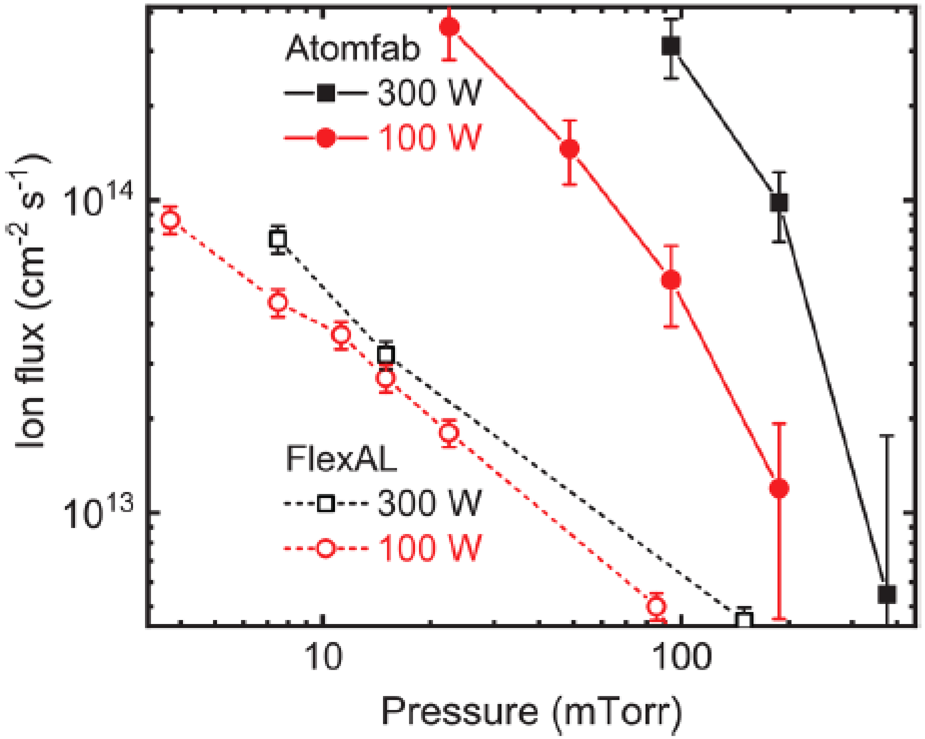


Image of the Oxford Instruments Atomfab system and RFEA installed in system.

Characterisation of a new low-damage remote plasma ALD system (Atomfab) for high-volume manufacturing of Al_2O_3 for GaN devices



IFEDFs for a range of chamber pressures at 200 W and plasma powers for O_2 plasma at 94 mTorr.



Ion flux as a function of pressure for FlexAL and Atomfab sources for O_2 plasmas of 100 and 300 W.

ALE Applications

A scalable, transfer free method to achieve horizontally individually patterned hetero-stacks

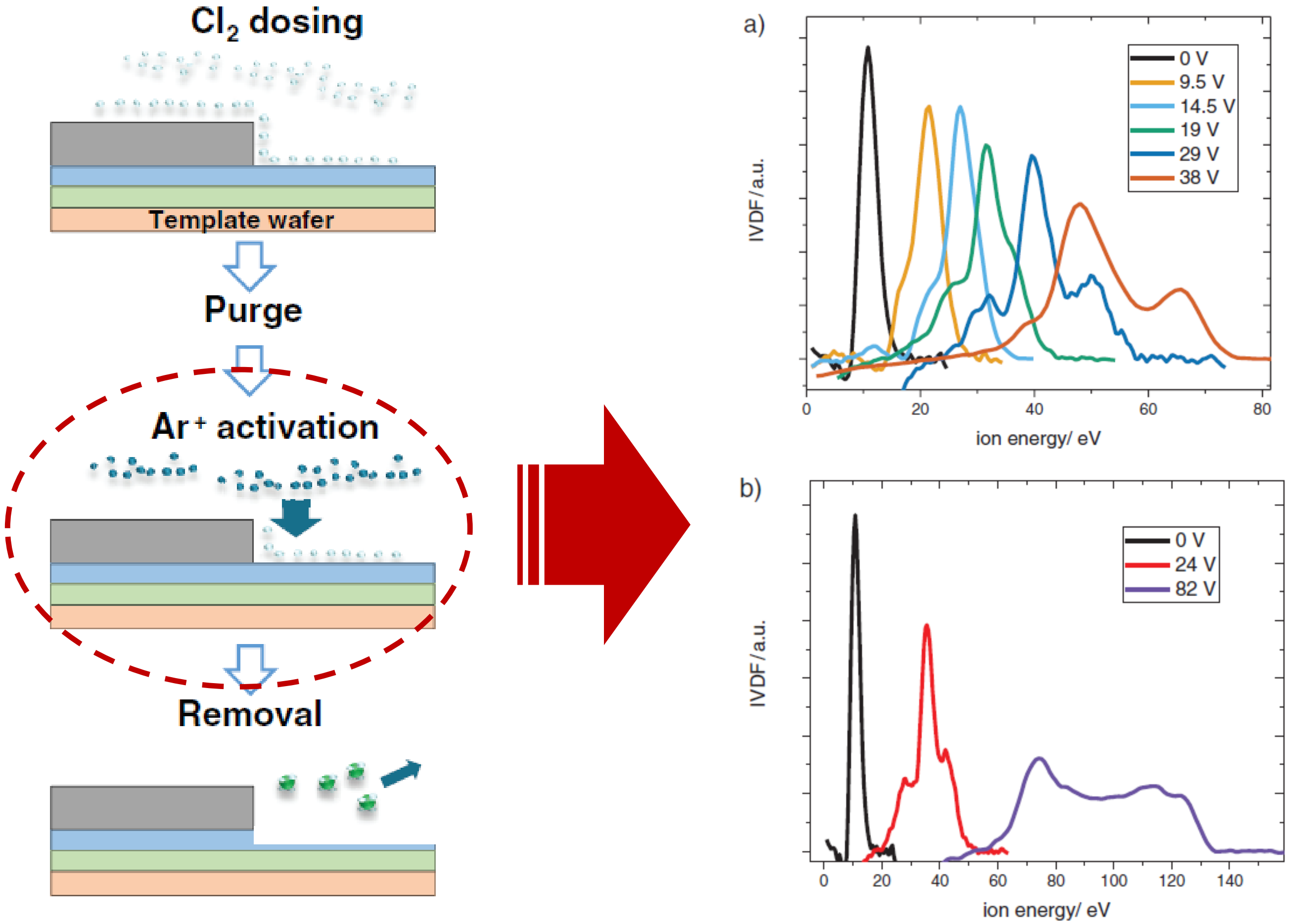
Oxford Instruments PlasmaPro 100 ALE

A route towards the fabrication of 2D hetero-structures using atomic layer etching combined with selective conversion

DOI: https://doi.org/10.1088/2053-1583/ab1ba7

In this work, atomic layer etching tool (ALE) is used to pre-pattern a sacrificial Si layer on top of MoS_2 multilayers, which is afterwards converted into a stack of two transition-metal dichalcogenides (TMD), using an Si-to-WS_2 conversion process.
To estimate the bias power impact in the most critical Ar plasma activation step, the ion velocity distribution functions were determined by a retarding field analyzer (RFEA).

Some example data is shown to the right



Schematic of the used ALE process and Ion velocity distribution functions for different set points of bias voltage for (a) low bias range and (b) high bias range.

Precise ion energy control with tailored waveform biasing

Precise ion energy control with tailored waveform biasing for atomic scale processing

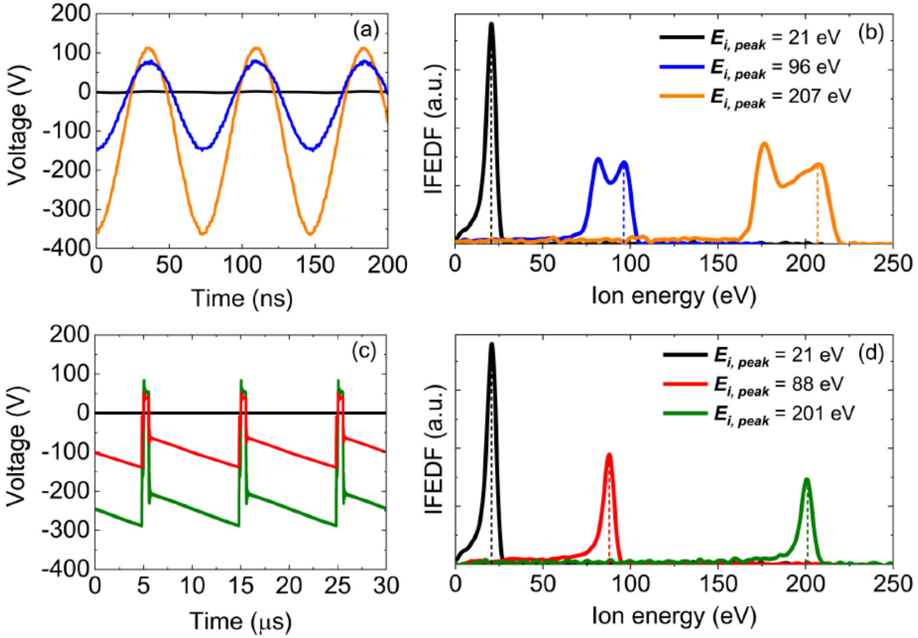
DOI: https://doi.org/10.1063/5.0028033

In this work, accurate control of the ion energy, independent of the ion flux, by means of Low Frequency (100 kHz) tailored bias voltage waveforms applied on dielectric substrates is reported in a commercial remote plasma reactor.

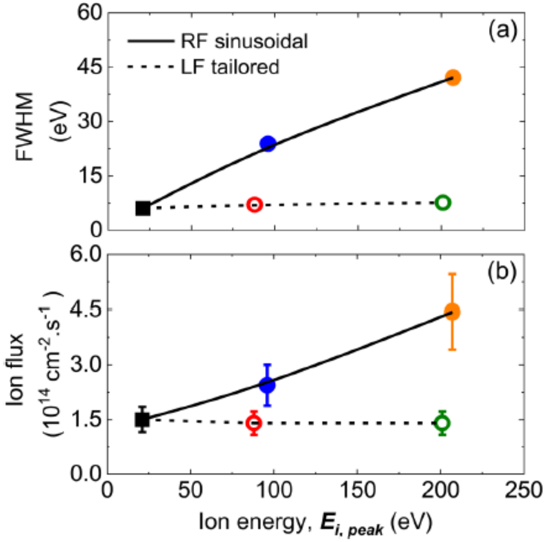
Some example data is shown to the right

Oxford Instruments FlexAL

1



2



1 (a) and (c) Substrate voltage as a function of time and (b) and (d) ion flux-energy distribution functions (IFEDFs) for grounded and biased SiO_2 substrates in an Ar plasma generated using 200 W remote plasma source power and 3 mTorr pressure.

2 (a) Full-width-at-half-maximum (FWHM) and (b) total ion flux for ion flux-energy distribution functions (IFEDFs)

Tailored voltage waveforms as a technique to control the ion bombardment energy

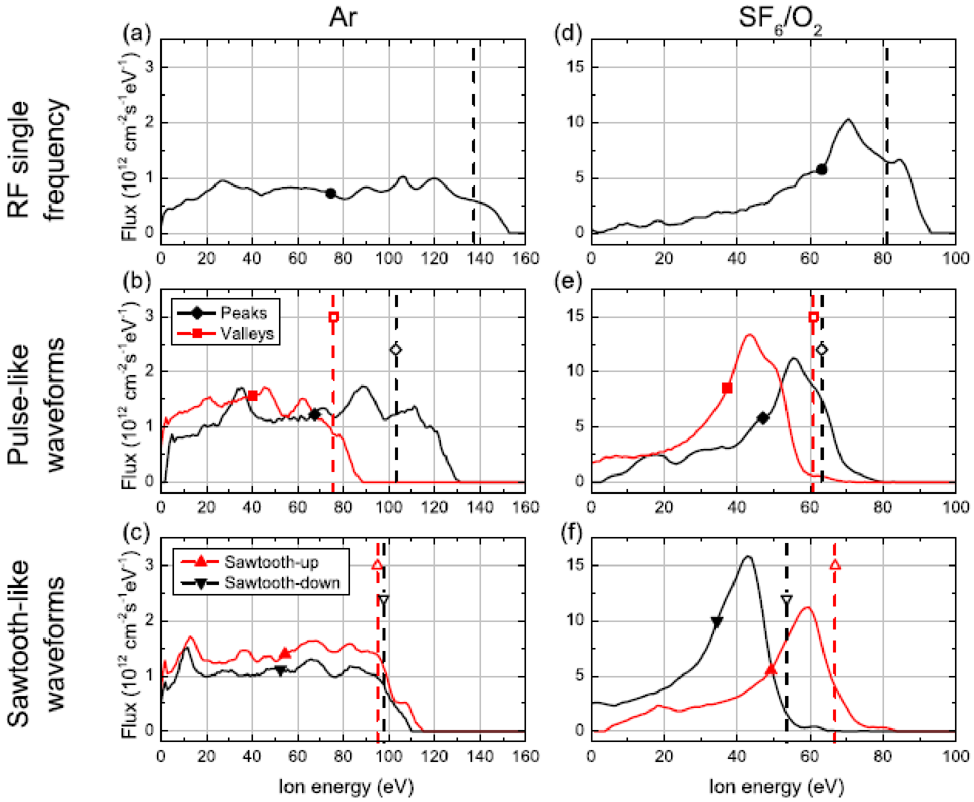
Excitation of Ar, O_2, and SF_6/O_2 plasma discharges using tailored voltage waveforms: control of surface ion bombardment energy and determination of the dominant electron excitation Mode

DOI: https://doi.org/10.1088/1361-6595/aaca05

The objective of this paper was to explore the limits of using Tailored voltage waveforms to manipulate the ion bombardment energy on a substrate in a reactive ion etching (RIE) system and for a range of SF_6/O_2 process conditions, paying particular attention to the relative importance of the amplitude and slope asymmetry effects.

Some example data is shown to the right

RIE CCP (Nanomaster NRE 3500)



Example of Ion energy distribution function (30 mTorr pressure and 25W power) in Ar (a)–(c) and SF_6/O_2 (d)–(f).

Tailored voltage waveform to produce ion energy distributions with one or two narrow peaks at selected energies

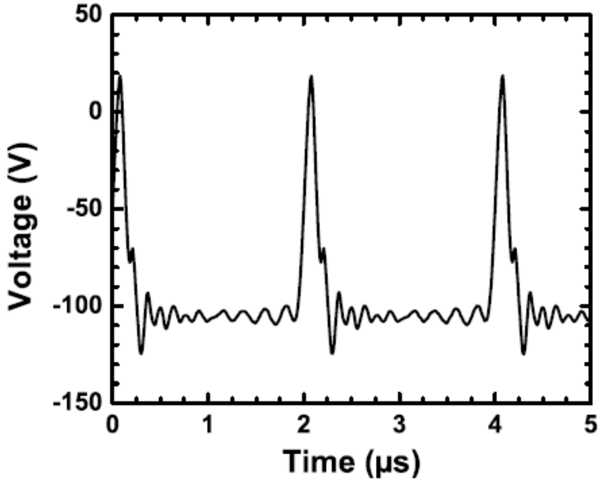
Tailored ion energy distributions at an rf-biased plasma electrode

DOI: https://doi.org/10.1088/0963-0252/19/6/065014

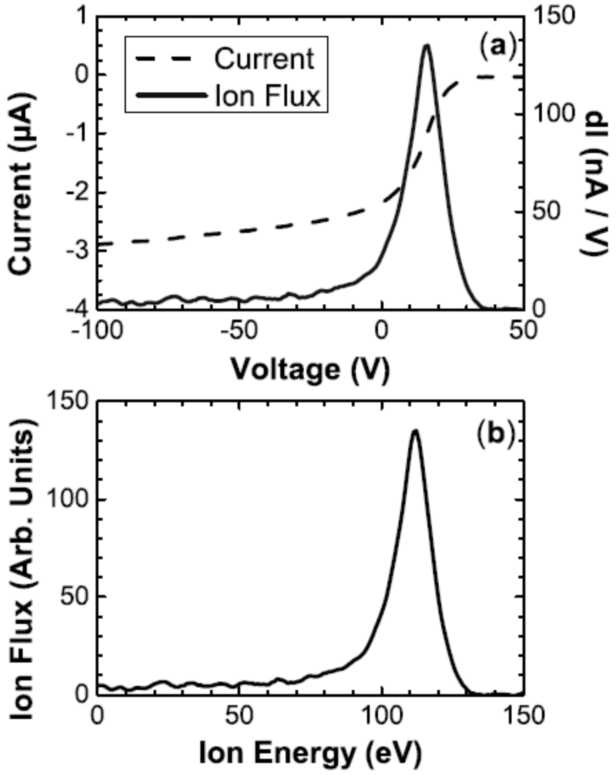
This paper confirms by the measurements of the incident IEDs at an rf-biased electrode in an Ar helicon plasma system that arbitrary IEDs may be produced by manipulating the shape of the bias voltage waveform in the collisionless sheath regime.

Some example data is shown to the right

Single-peak tailored waveform

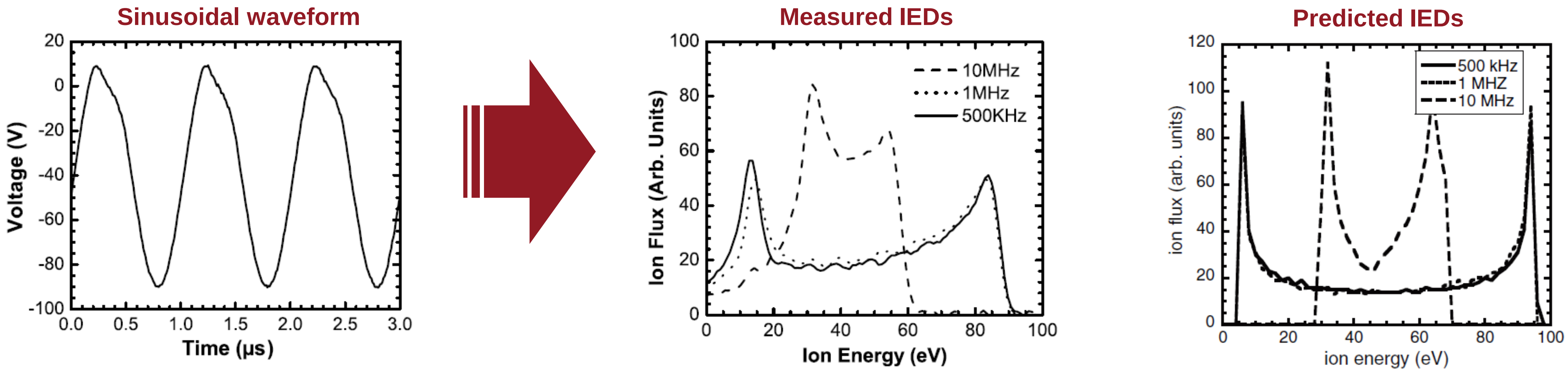


Helicon Plasma



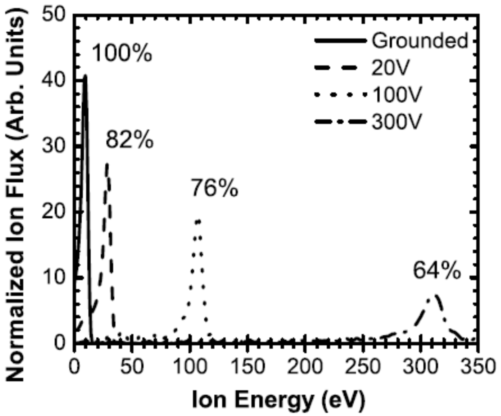
Example of a tailored waveform with a single voltage level at approximately 100V to produce an IED with a single narrow peak at near 100 eV. (Helicon plasma (13.56 MHz) 10mTorr and 300W)

Tailored voltage waveform to produce ion energy distributions with one or two narrow peaks at selected energies

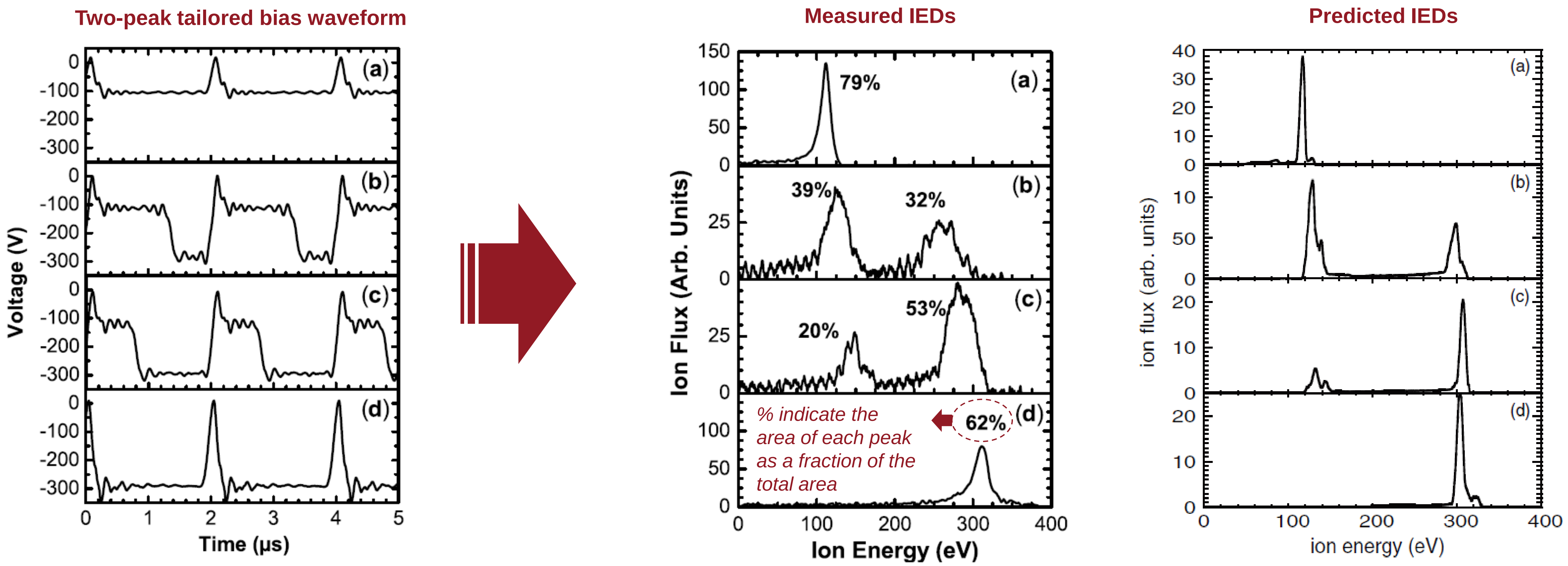


Example of sinusoidal electrode bias voltage waveform with a peak-to-peak magnitude of approximately 100V and frequency of 1 MHz along with corresponding measured and predicted IEDs for 500 kHz, 1MHz and 10 MHz.

IEDs for a grounded electrode, 20, 100 and 300V single-level electrode bias voltage waveforms at 300W helicon power and 10mTorr pressure.



Tailored voltage waveform to produce ion energy distributions with one or two narrow peaks at selected energies



% indicate the area of each peak as a fraction of the total area

Example of Two-peak tailored bias waveform with two levels of 100V and 300 V with the duty cycle, or relative duration of the two levels, was varied in approximate ratios (a) 1 : 0, (b) 2 : 1, (c) 1 : 2, (d) 0 : 1. Also shown the corresponding measured and predicted IEDs.

Optimization of ALE using RF-ICP with RF bias in an Ar/C_4F_6 mixture

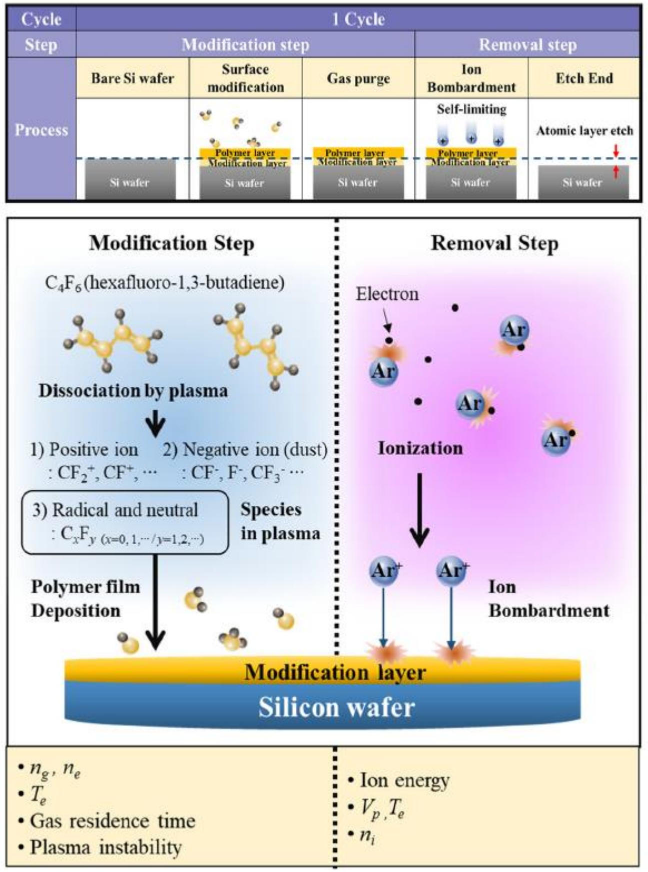
Discharge physics and atomic layer etching in Ar/C4F6 inductively coupled plasmas with a radio frequency bias

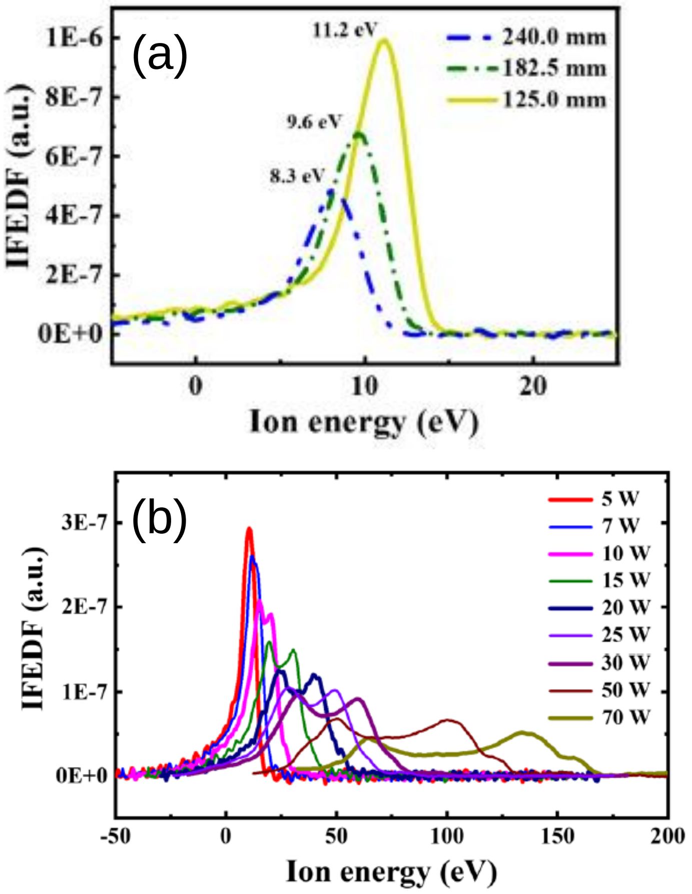
DOI: https://doi.org/10.1063/5.0047811

In this study, the discharge characteristics of an Ar/C_4F_6 mixture plasma for the modification and removal steps in ALE were investigated, and the ALE recipe and processing conditions were set based on the understanding of these plasma physics.

Some example data is shown to the right

Fluorocarbon-based ALE comprising a modification step and a removal step.





IFEDF with (a) antenna-electrode gap and (b) the RF bias power of 12.56 MHz at the ICP power of 1 kW, flow rate of 20 sccm of Ar gas, and pressure of 50 mTorr.

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