

Semion Pulsed RF (ICP) Applications

Measure the Ion Flux and Ion Energy incident on your substrate

https://www.impedans.com/semion_sensors



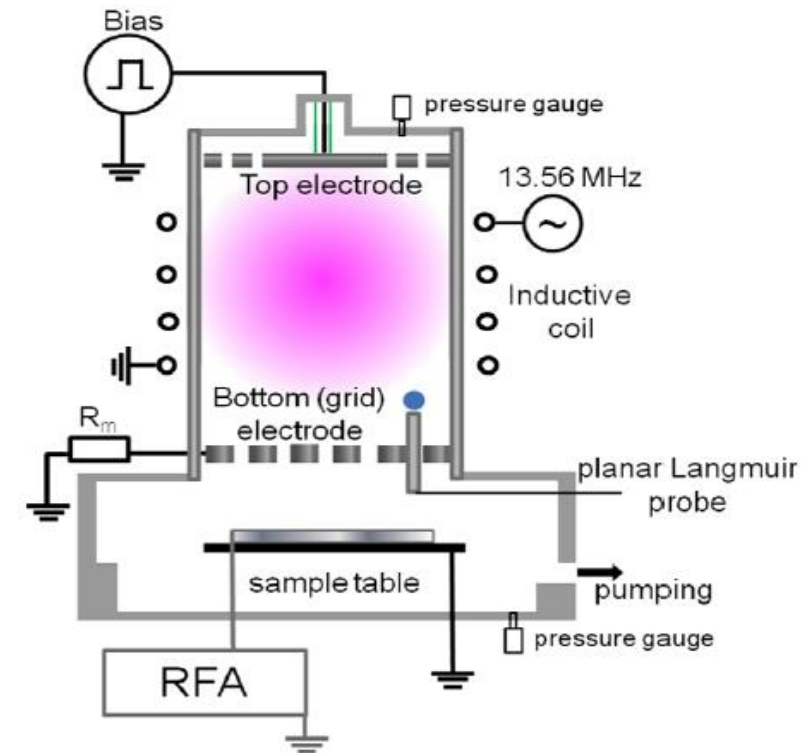
Extraction and acceleration of positive and negative ion beams from a pulsed inductively coupled plasma in SF_6

Extraction and neutralization of positive and negative ions from a pulsed electronegative inductively coupled plasma

Marinov D et al, Department of Physical Sciences, The Open University, UK
LPP, Ecole Polytechnique, CNRS, UPMC, Université Paris-Sud, France
IMEC, Belgium
Department of Electrical Engineering and Electronics, University of Liverpool, UK

DOI: <https://doi.org/10.1088/0963-0252/24/6/065008>

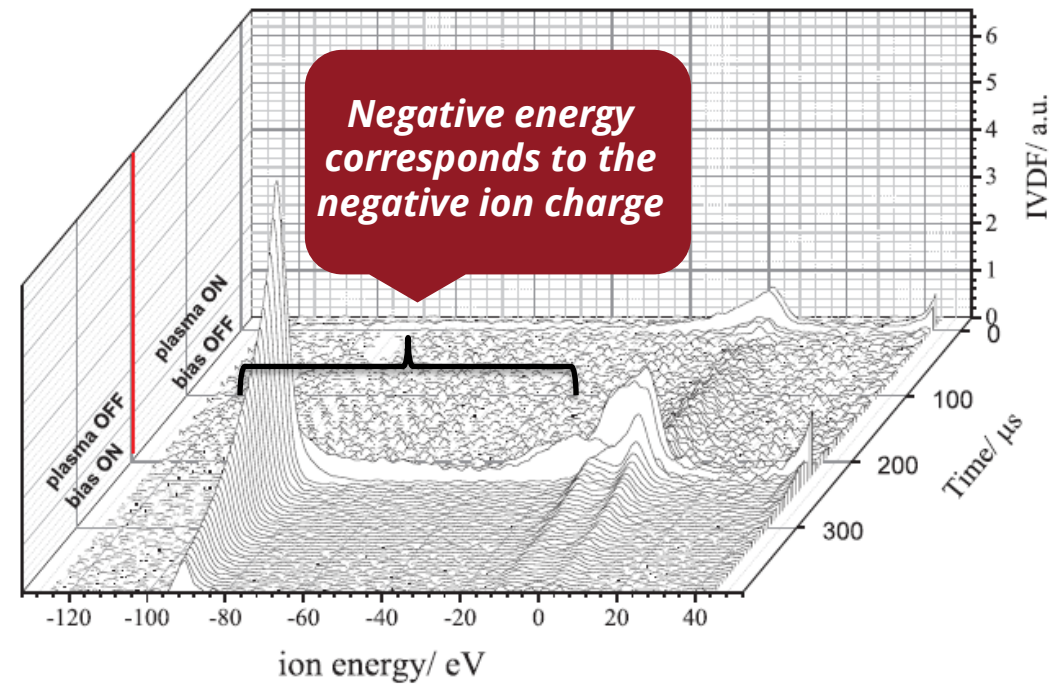
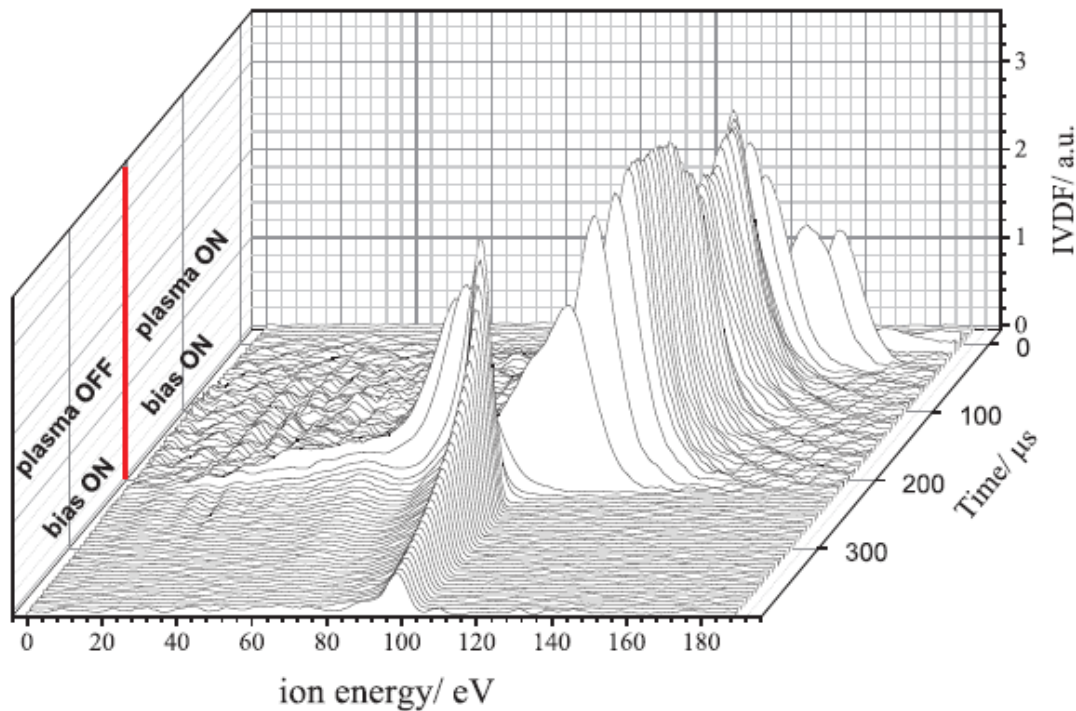
This work investigates the extraction of positive and negative ions from a pulsed inductively coupled plasma (ICP) in SF_6 bounded by two independently biased electrodes (with one of the electrodes fitted with an extraction grid). Time-resolved velocity distributions of extracted ions were measured synchronously with the variation of the plasma potential.



Oxford Instruments PlasmaLab80 (PL80) reactive ion etching system – ICP source.

Extraction and acceleration of positive and negative ion beams from a pulsed inductively coupled plasma in SF₆

SF₆ at 3.3 Pa, modulation frequency 2 kHz, pulse duration $\tau_{\text{pulse}} = 200 \mu\text{s}$, peak RF power $P_{\text{RF}} = 400 \text{ W}$

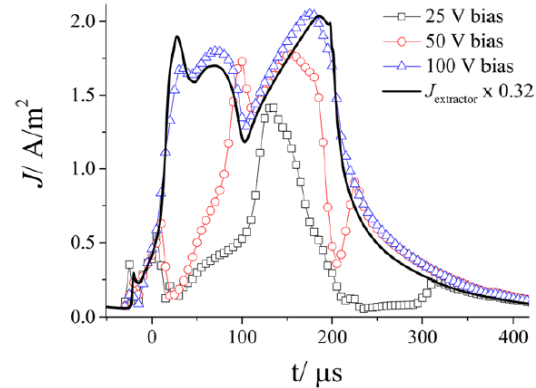


Time-resolved IVDF of the positive ion beam extracted from a pulsed discharge.

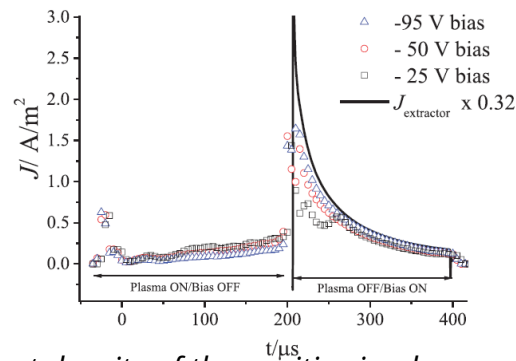
(a) A continuous bias voltage $U_{\text{bias}} = 100 \text{ V}$.

(b) A pulsed bias voltage $U_{\text{bias}} = -95 \text{ V}$.

Extraction and acceleration of positive and negative ion beams from a pulsed inductively coupled plasma in SF₆

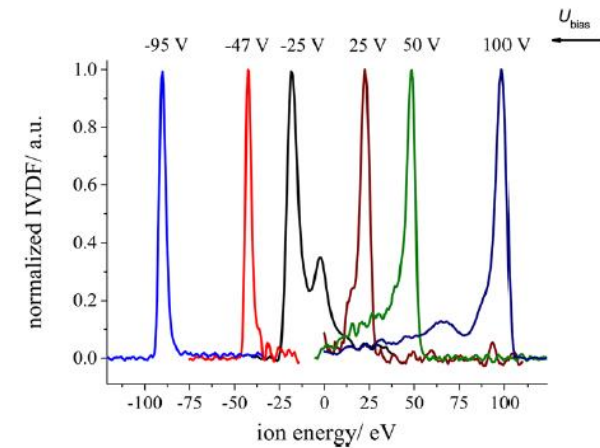


Continuous bias voltage was 25 V, 50 V and 100 V.

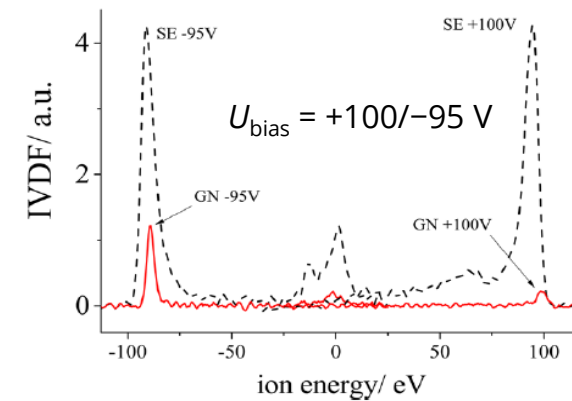


Pulsed bias voltage amplitude -25 V, -50 V and -95 V.

Current density of the positive ion beam measured using the Semion RFA (open symbols) and the current density on the extractor multiplied by the transparency of the extraction grid (solid line).



Normalized IVDF of positive and negative ions extracted with different bias voltage measured 75 μs after the end of the discharge pulse.



IVDF of ions extracted with the graphite neutralizer (GN) and the stainless steel grid extractor (SE).

Pulsed ICP in SF₆ $p = 3.3$ Pa, $P_{RF} = 400$ W

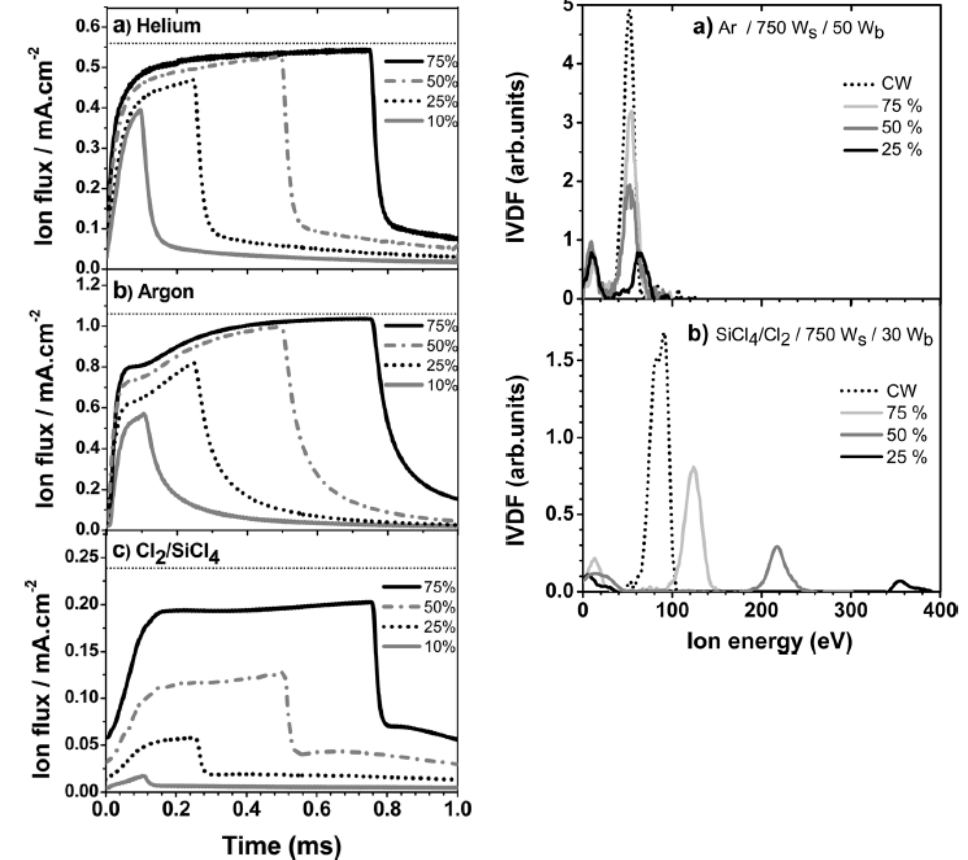
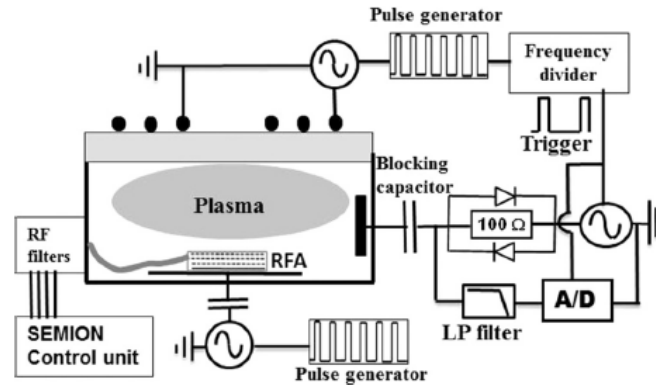
Impact of pulsed ICP operated over a range of duty cycles

Ion flux and ion distribution function measurements in synchronously pulsed inductively coupled plasmas

Brihoum M et al, Laboratoire des Technologies de la Microélectronique CNRS, France
Impedans Ltd., Ireland
The Open University, Walton Hall, United Kingdom

DOI: <https://doi.org/10.1116/1.4790364>

In this paper, authors reported experimental measurements of the impact of the duty cycle on the time variations of the ion flux and on the time averaged ion distribution function measured at the wafer surface in an ICP (13.56 MHz) processing chamber subject to pulse modulation of source excitation and bias at 1 kHz, in several plasma chemistries.



Experimental setup and example of the ion flux and IVDF measured in synchronously pulsed ICP plasma operating in rare gas (Ar or He) and reactive SiCl₄/Cl₂ plasmas.

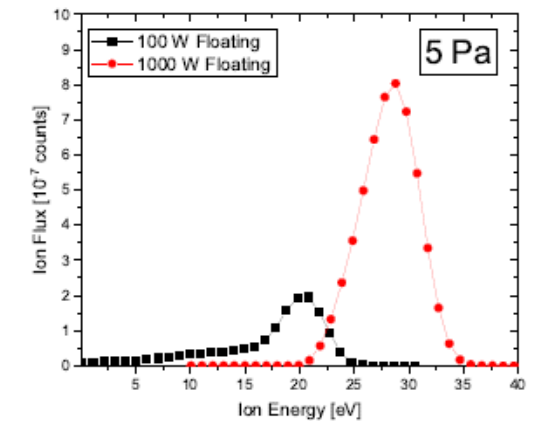
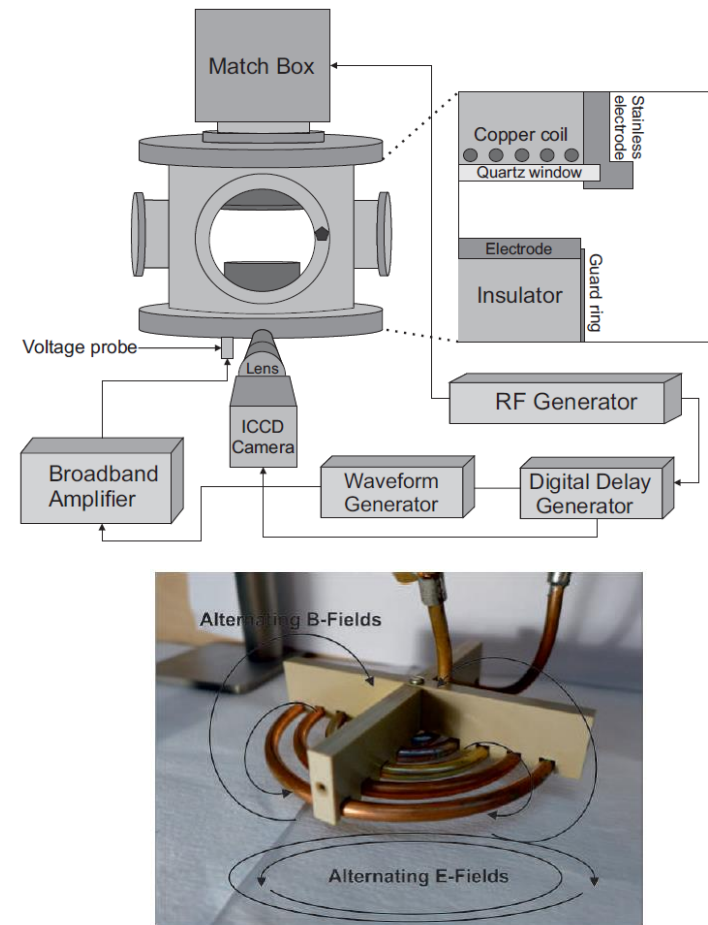
Measuring IEDF and Ion Flux at the plasma surface interface in ICP

Plasma dynamics at the surface interface in radio frequency Discharges

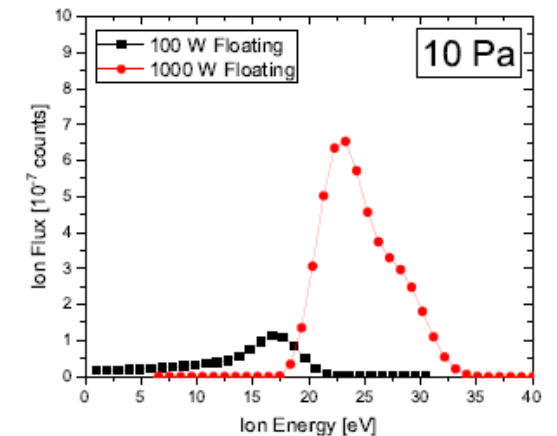
Martin Paul Blake, University of York, UK

DOI: https://etheses.whiterose.ac.uk/25781/1/Martin_Blake_July_2019_PhD.pdf

Measurements in this work looks at the ion energy distribution at the plasma-surface interface (13.56 MHz ICP), highlighted the impact of varying the Tailored Voltage Waveform's voltage, polarity and repetition. By reducing the pulse width it reduced the impact on the ion properties due to the fast change in applied voltage.



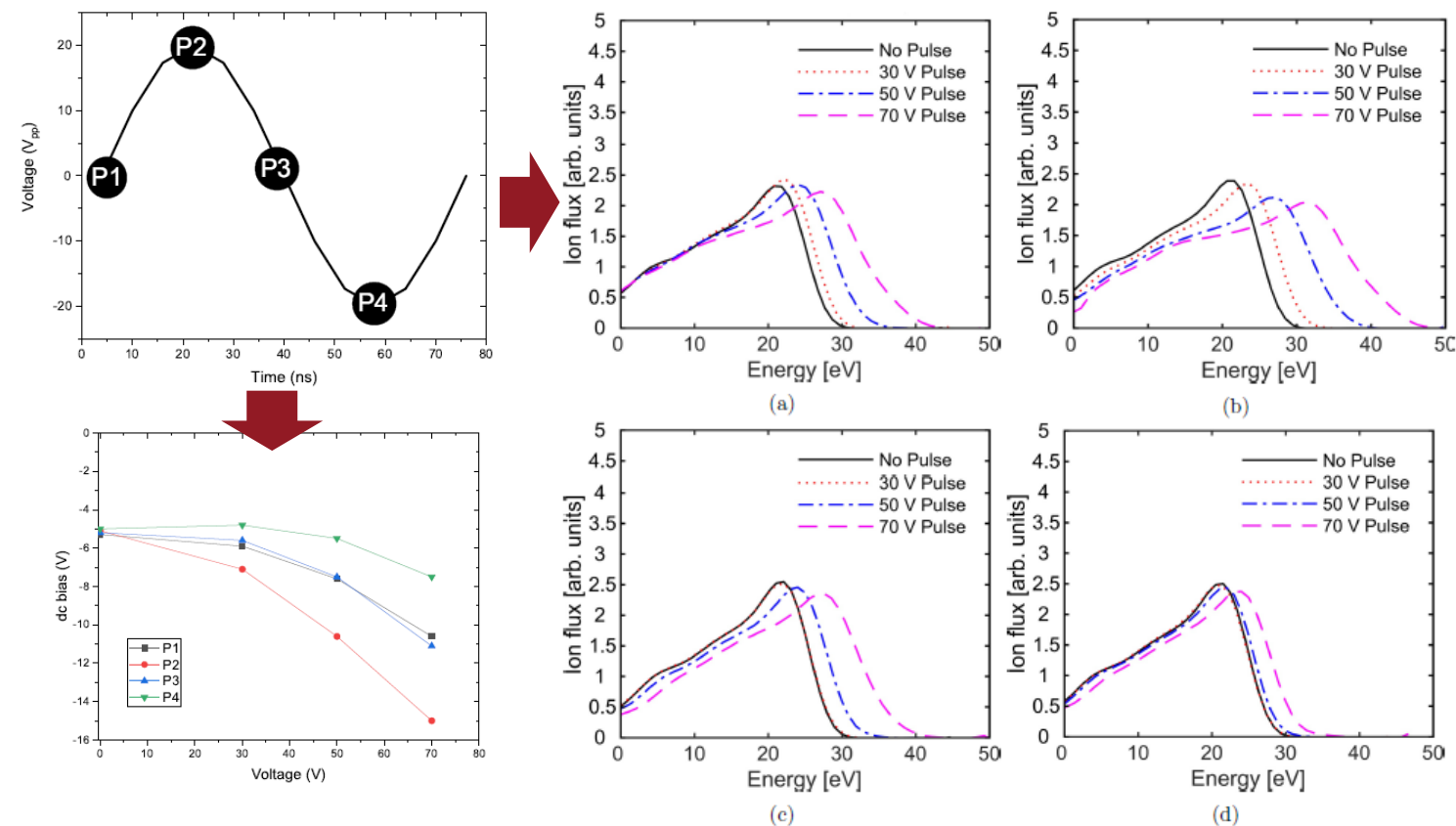
(a)



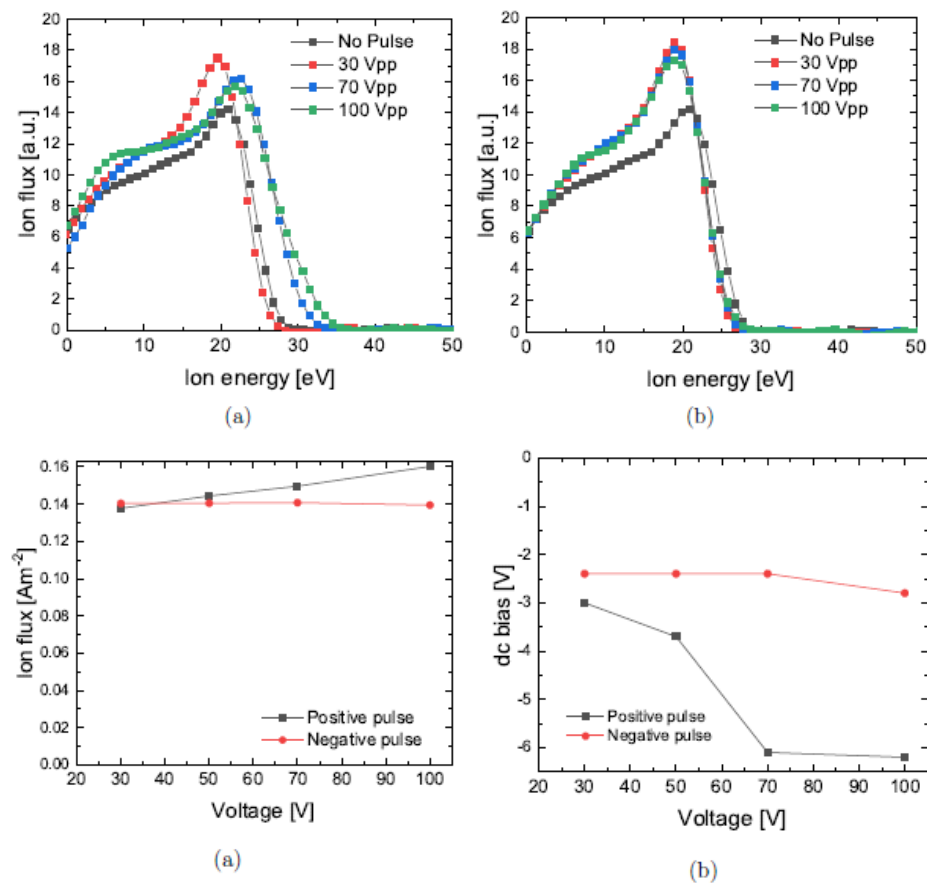
(b)

Experimental setup and Floating lower electrode comparison of a 100 W E-mode (black dotted lines) to 1000 W H-mode (red dotted lines) IEDFs at 5 Pa and 10 Pa. Also shown electric (E) and magnetic (B) fields in the planar ICP configuration, with field lines and direction indicated by the arrows.

Measuring IEDF and Ion Flux at the plasma surface interface in ICP

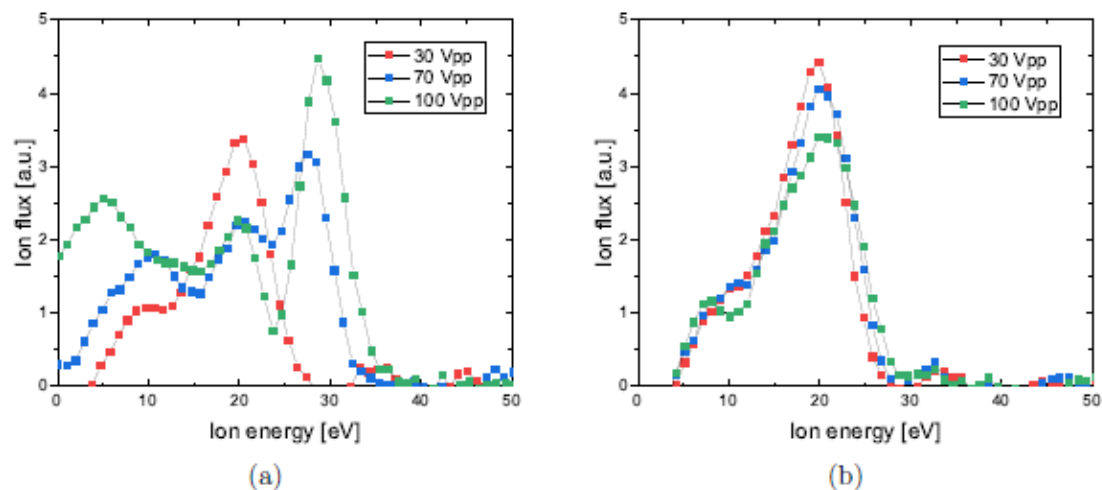


IEDF measurements of a positive pulse at the four phase positions P1 (a), P2 (b), P3 (c) and P4 (d). The plasma is operated at 50 W in a 1:2 Ar/O₂ gas mixture, with a system pressure of 10 Pa.

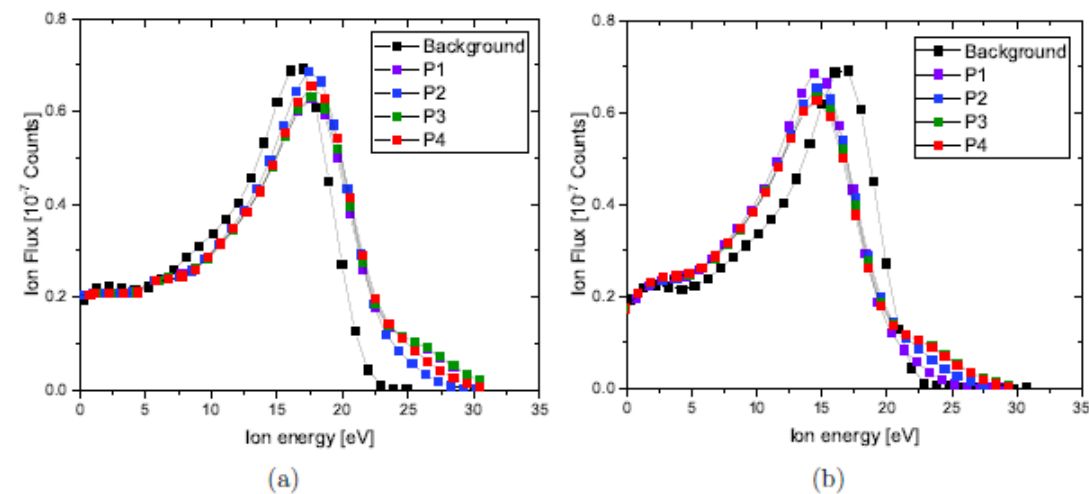


Ion energy, ion flux and DC self-bias for a positive (a) and negative (b) pulse voltage variation. The plasma is operated at 50 W with a pressure of 10 Pa and gas mixture of O₂/Ar (98% / 2%). Pulse voltage is 100 V_{pp}.

Measuring IEDF and Ion Flux at the plasma surface interface in ICP

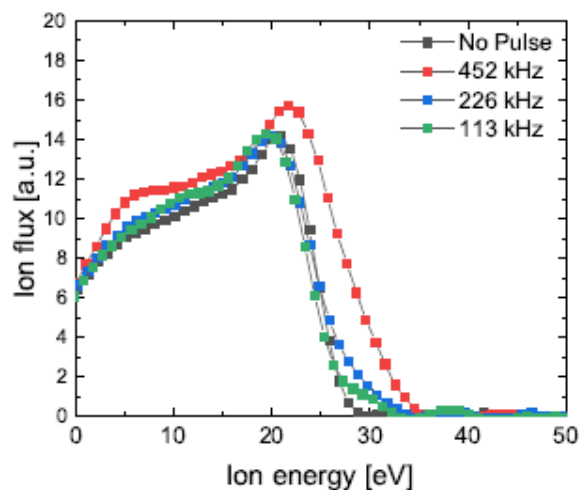


Positive (a) and negative (b) pulse voltage variation with the background ion flux subtracted from each pulse voltage plot. The plasma is operated at 50 W with a pressure of 10 Pa and gas mixture of O_2/Ar (98% / 2%). Pulse voltage is 100 V_{pp}.



Ion energy data taken for a positive (a) and negative (b) polarity pulse at the four phase positions. The plasma is operated at 50 W with a pressure of 10 Pa and gas mixture of O_2/Ar (98%/2%), with a pulse voltage of 100 V_{pp}.

Ion energy data taken for different repetition rates 452, 226 and 113 kHz.



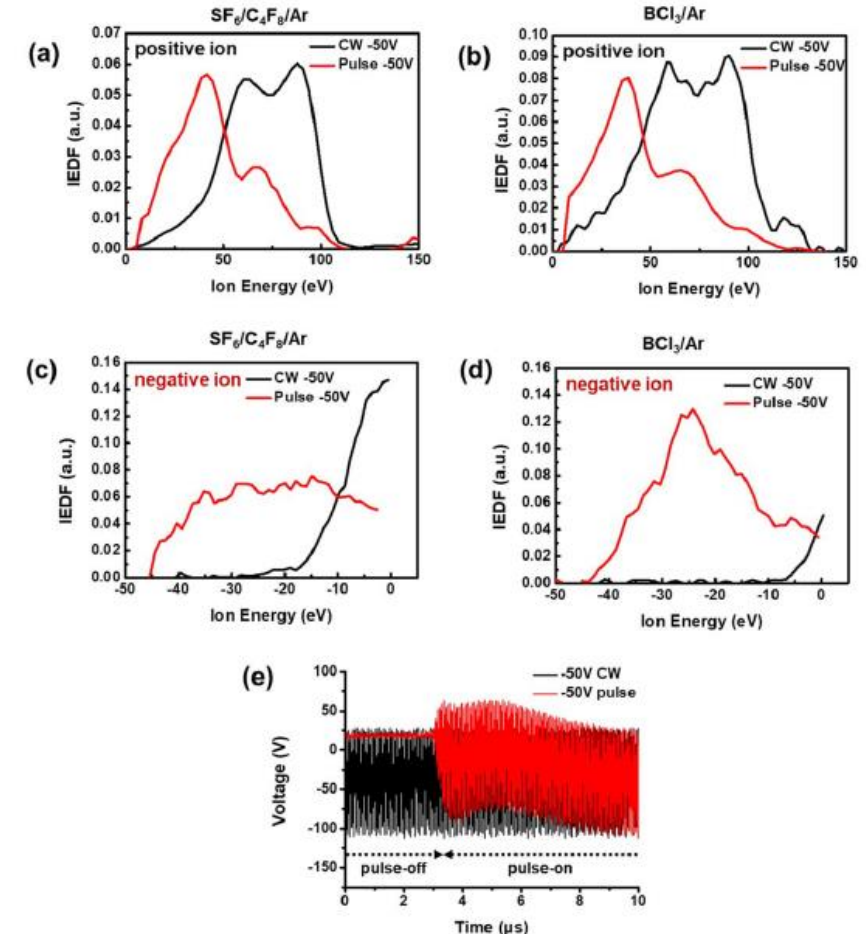
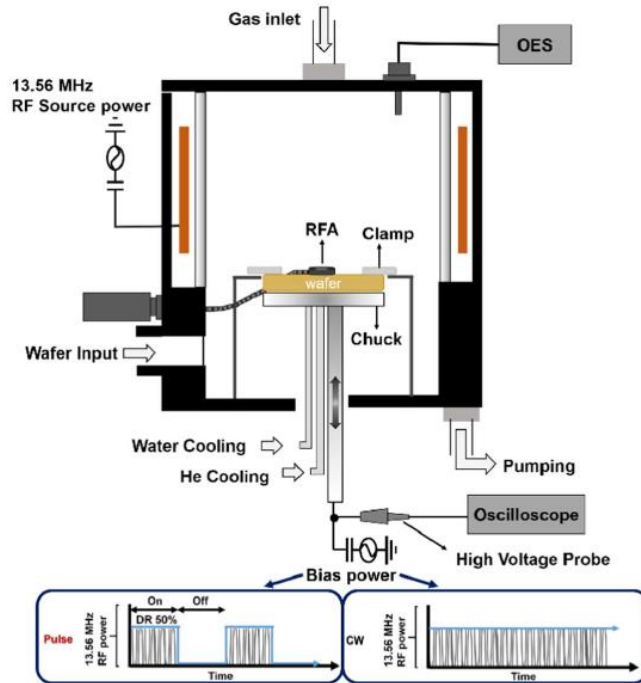
Fabrication of optical metamaterials on glass substrates formed using inductively coupled plasma (ICP) etching

Etch characteristics of Si and TiO_2 nanostructures using pulse biased inductively coupled plasmas

Soo-Gang Kim et al, SKKU Advanced Institute of Nanotechnology (SAINT), SKKU, Republic of Korea
School of Advanced Materials Science and Engineering, SKKU, Republic of Korea
Department of Advanced Materials, Daejeon University, Republic of Korea
Nano Electronics Laboratory, Samsung Advanced Institute of Technology, Samsung Electronics Co. Ltd., Gyeonggi-do Korea

DOI: <https://doi.org/10.1088/1361-6528/ab7c75>

In this work, the effects of the pulse biased ICP etching on the plasma characteristics and etch characteristics of Si and TiO_2 was investigated and the results were compared with those generated from CW biased ICP etching.



Experimental setup with (a-d) Positive and negative IEDFs to the substrate during pulsed and CW operation. (e) rf voltage shapes measured with 13.56 MHz rf power to the substrate with a $\text{SF}_6/\text{C}_4\text{F}_8/\text{Ar}$ plasma (-50 V of DC-bias voltage during power-on).

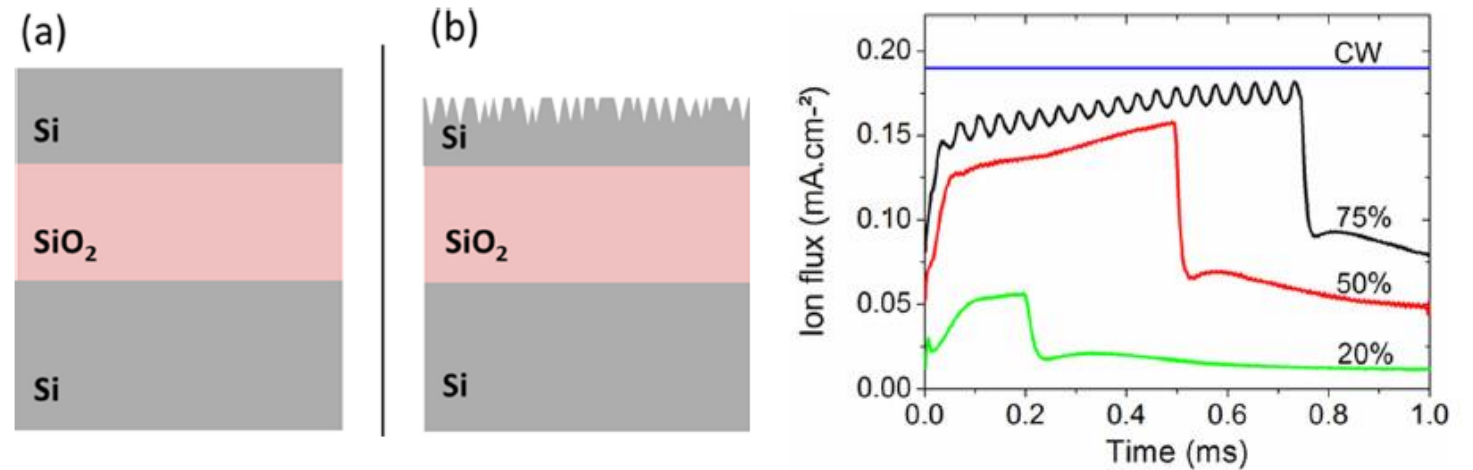
Exploring the source of the roughening in pulsed Cl_2 plasmas

Roughness generation during Si etching in Cl_2 pulsed plasma

Odile Mourey et al, Univ. Grenoble Alpes, CNRS, CEA-Leti Minatec, LTM, France

DOI: <https://doi.org/10.1116/1.4951694>

In this work, experiments are performed as a function of duty cycle and etched depth. A rise of the R_{max} roughness with the etched depth is observed after etching with low duty cycle conditions, the roughness being not created by micro-masking.



Schematic of the model before etching (left) and after etching (right). Example of the time variations of the ion flux in a synchronously pulsed Cl_2 plasma for several duty cycles (ICP-pulsed in a SiOCl coated chamber).

Measurement of Ion Flux and Ion Energy for changing pulsing frequency and bias power in a pulsed HBr/O₂ etch plasma

- **Development of etch processes based on pulsed reactive plasmas pulsed plasmas for etch applications**

Moritz Haass, Université de Grenoble, France

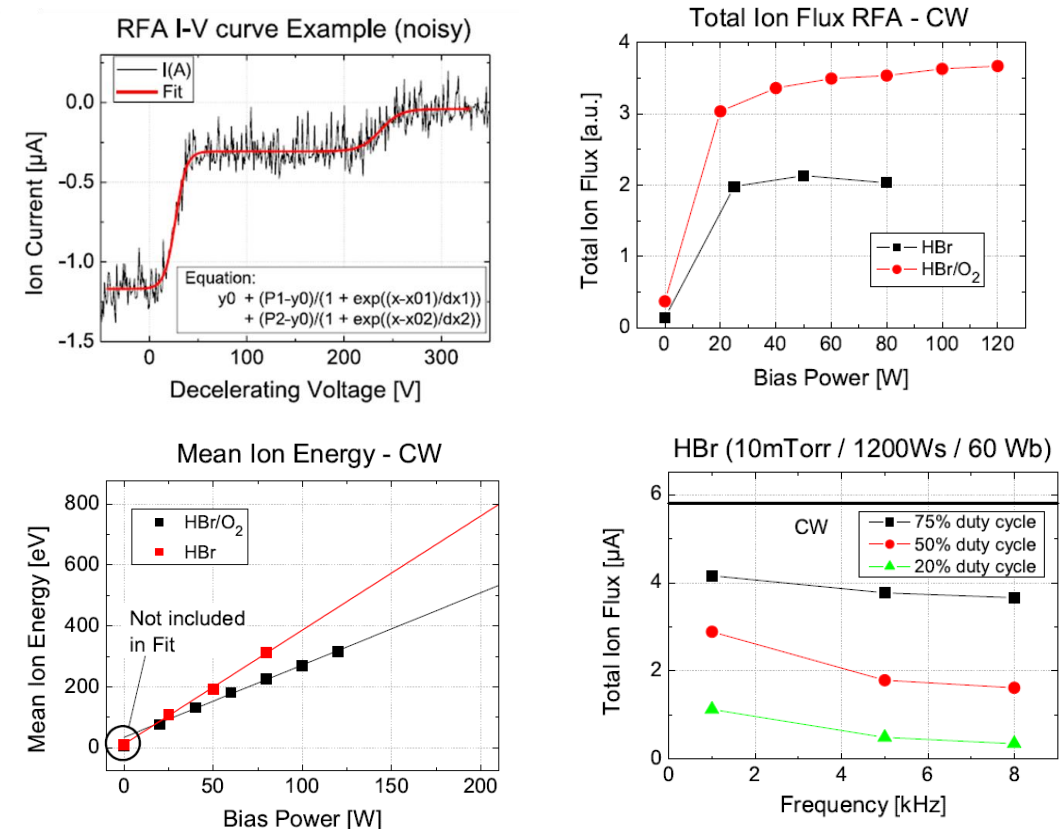
DOI: <https://tel.archives-ouvertes.fr/tel-00820065>

- **Silicon etching in a pulsed HBr/O₂ plasma.**
I. Ion flux and energy analysis

Moritz Haass et al, LTM (CNRS/UJF-Grenoble1/CEA), France
Impedans Ltd., Ireland

DOI: <https://doi.org/10.1116/1.4917230>

The objective of this work was to investigate the impact of synchronous pulsing on silicon etching in a HBr/O₂ plasma. The characterisation of plasma properties include measurement of ion flux, ion energy and ion energy distribution function.



Examples of the Ion energy and ion flux with power and pulsing frequency variation

IED in compact ICP Argon plasma with and without a Faraday shield

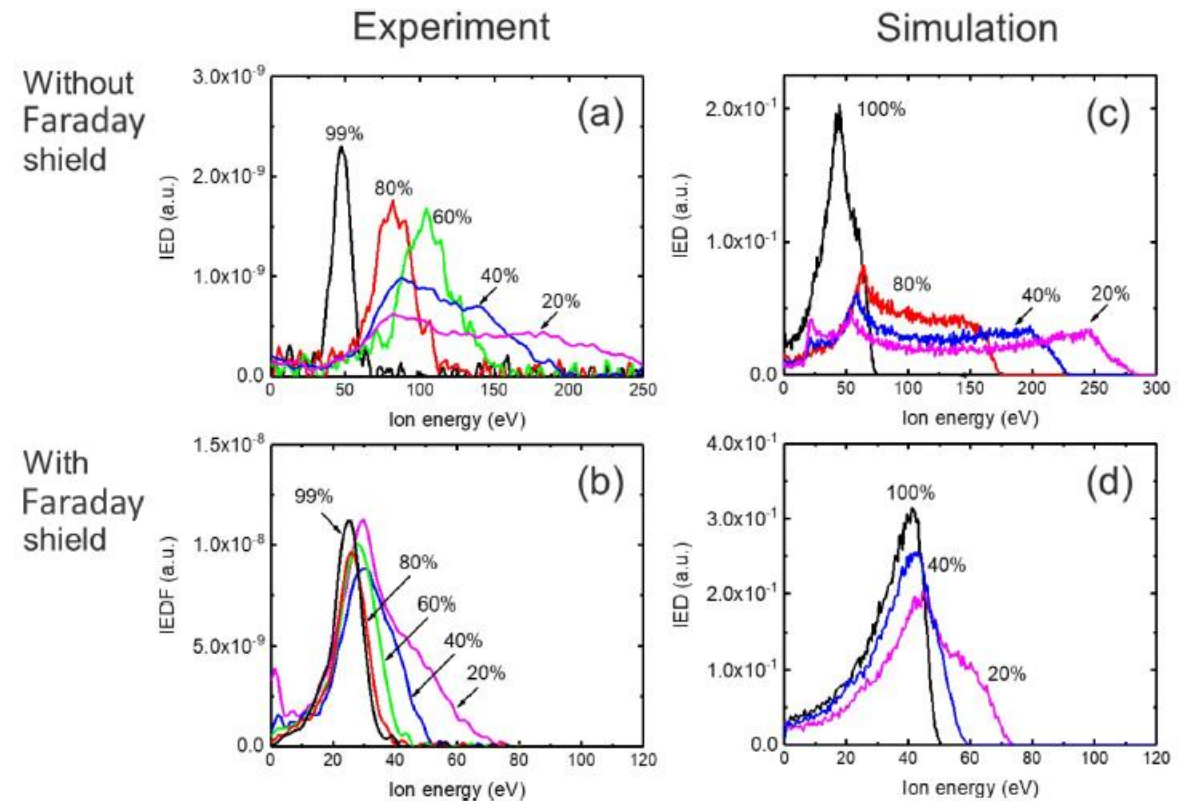
Factors influencing ion energy distributions in pulsed inductively coupled argon plasmas

Zhiying Chen et al, Tokyo Electron America, USA
Tokyo Electron Miyagi Ltd., Japan

DOI: <https://doi.org/10.1088/1361-6463/ab8b08>

In this work, authors investigate the origin of important features of ion energy distributions during pulsing.

Ion energy distributions (IEDs) were measured for a range different duty cycles using source pulsing with a coaxial coil inductively coupled plasma source with and without a Faraday cage to isolate capacitive coupling. The effect of duty cycle on the IEDF is discussed using simulation results for context.



Example of measured and simulated IEDs for different RF duty cycles under pulsed plasma conditions with time average power of 150 W and pressure of 20 mT (2.67 Pa) without a Faraday shield (a) and with a Faraday shield (b).

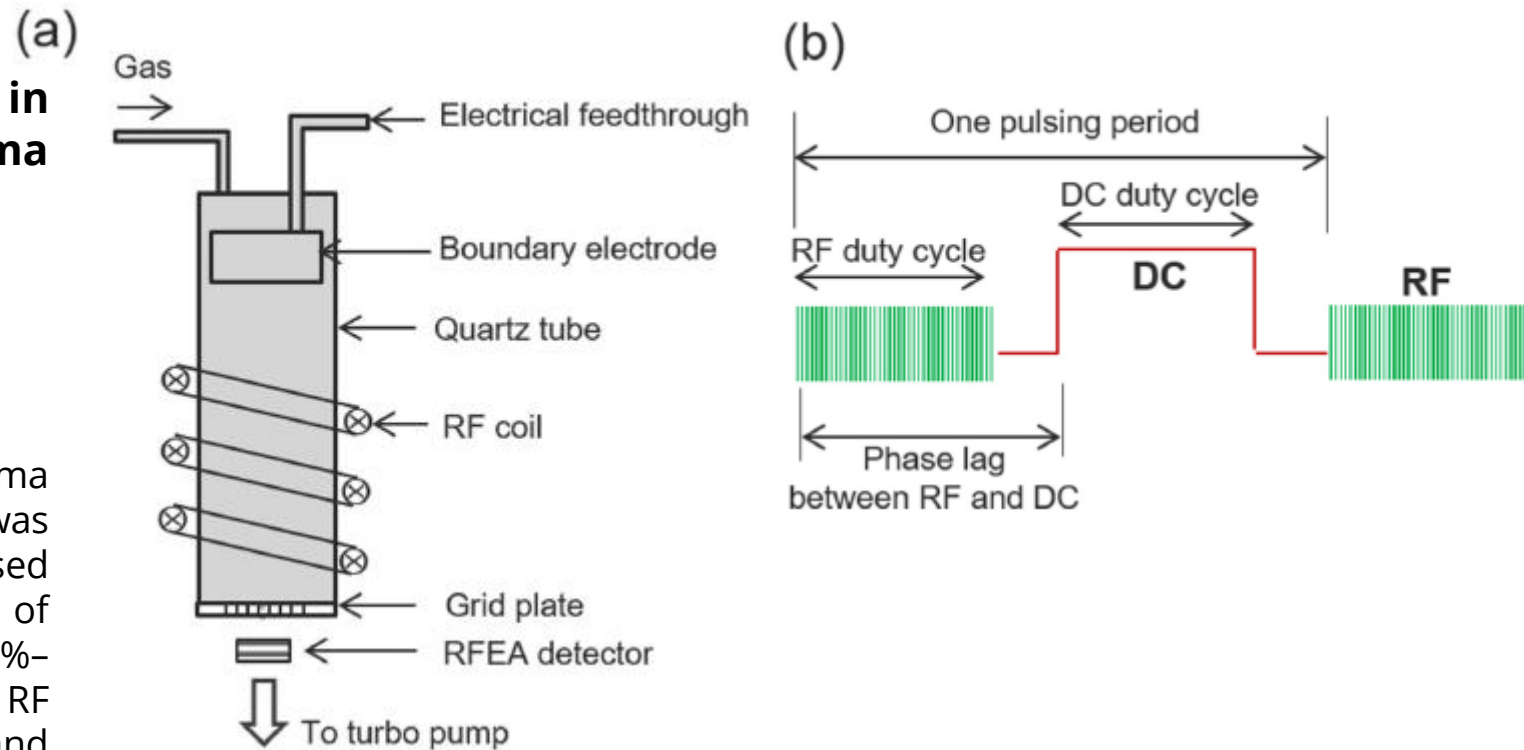
IEDFs and ion flux measurement on advanced plasma diagnostic (APD) system developed using a ICP source

Time-resolved ion energy distribution in pulsed inductively coupled argon plasma with/without DC bias

Zhiying Chen et al, Tokyo Electron America, Inc., USA

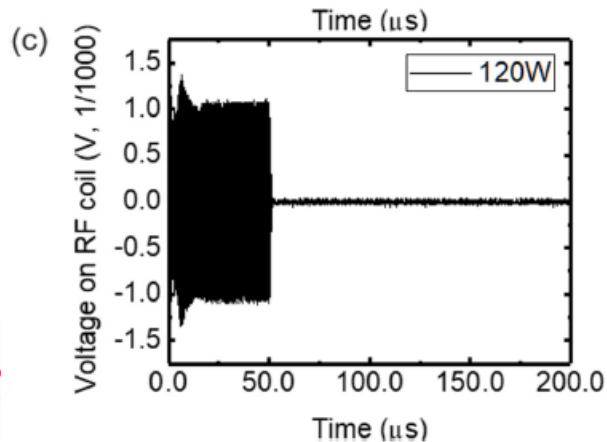
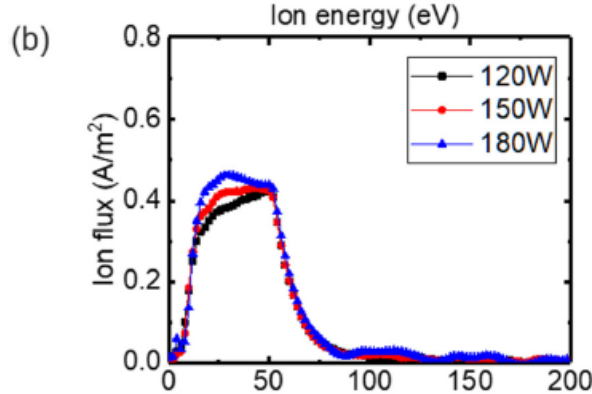
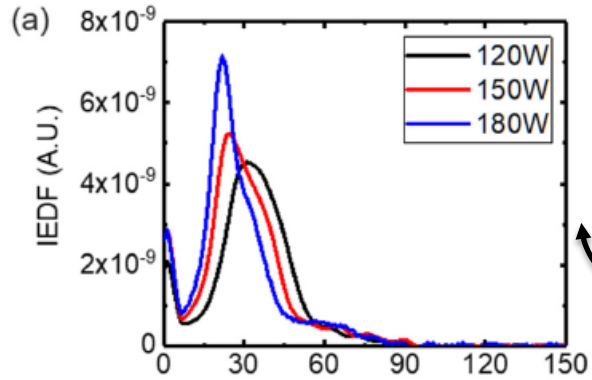
DOI: <https://doi.org/10.1116/6.0001737>

In this work, a compact inductively coupled plasma system with a RF source frequency of 13.56 MHz was developed to diagnose the general behavior of biased high density Argon plasmas. They report the effect of the pulse frequency (2–10 kHz), RF duty cycle (25%–75%), DC duty cycle (5%–50%), phase lag (50–60 μ s), RF power (120–180 W), DC bias voltage (0–150 V), and discharge pressure (20–80 mTorr) on the IEDFs and ion flux over a pulse period on the plasma system. The time-resolved IEDFs and ion flux were measured using a retarding field energy analyzer.

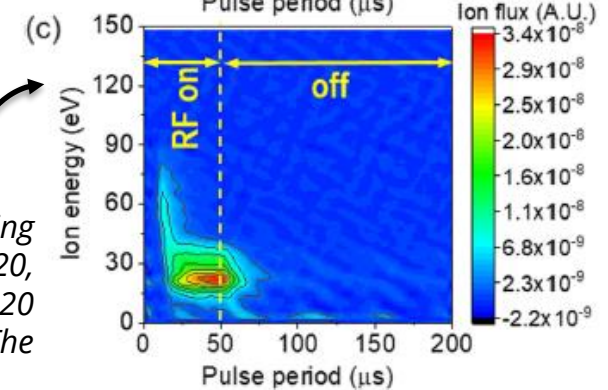
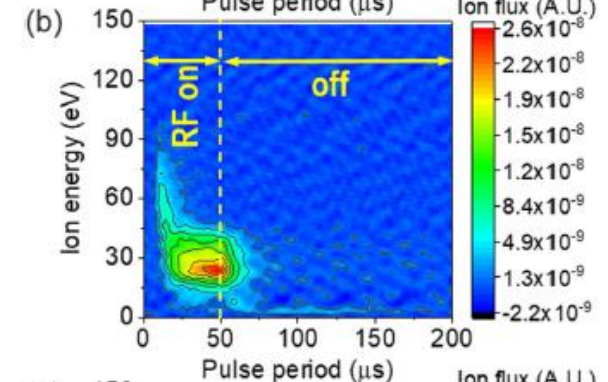
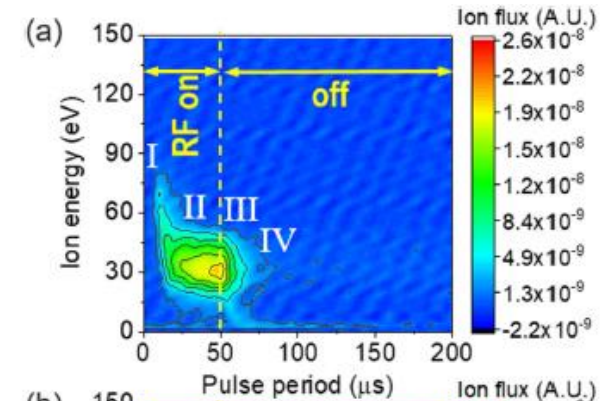


(a) Schematic of the RF inductively coupled plasma source. The plasma is ignited by a Golden-cooled RF coil in a quartz tube. A slotted 316 SS cylindrical sleeve serves as a boundary electrode to control ion energy distributions. The ions are extracted by a grounded grid plate located at the bottom of plasma source. Gas is introduced from the top of source. (b) The plasma is modulated by RF source pulsing and RF-DC synchronized pulsing at different RF powers, DC bias voltages, discharge pressures, and pulse frequencies with various RF and duty cycles, as well as phase lags.

IEDFs and ion flux measurement on APD: A. RF Source Pulsing- RF Power



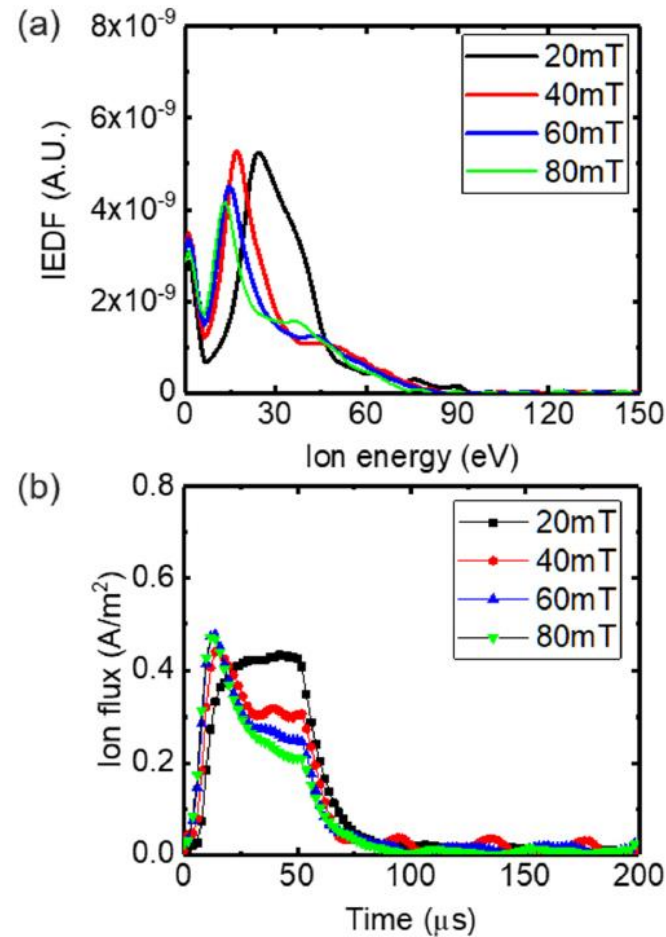
(a) Time-averaged IEDF and (b) time-resolved ion flux during one plasma pulsing period with different averaged RF powers. The pressure is 20 mTorr and the pulse frequency is 5 kHz. The RF duty cycle is 25%. (c) The time-resolved RF coil voltage for averaged RF power of 120 W.



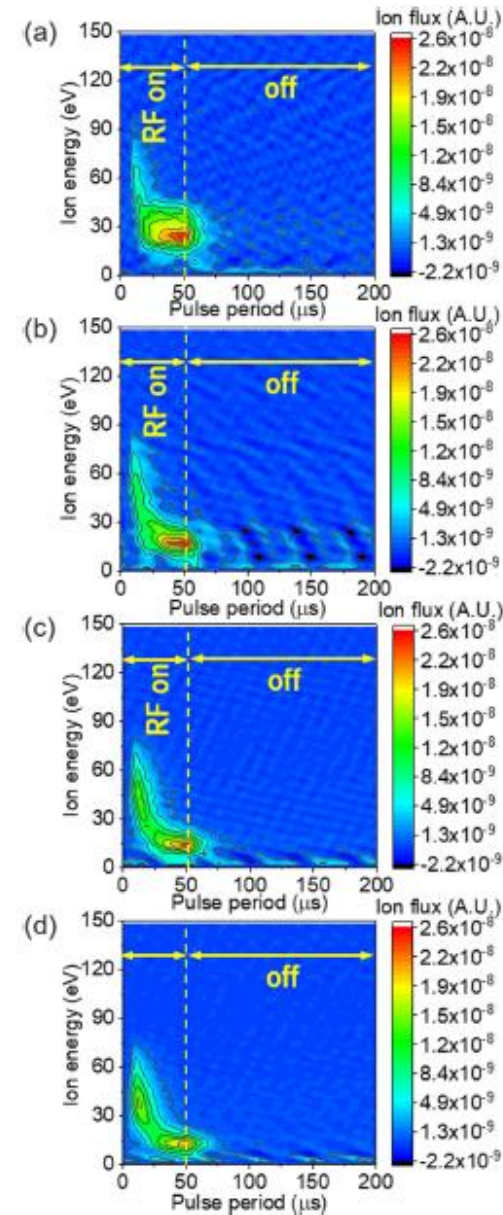
Time-resolved IEDF during one plasma pulsing period with the averaged RF power of (a) 120, (b) 150, and (c) 180 W. The pressure is 20 mTorr, and the pulse frequency is 5 kHz. The RF duty cycle is 25%.



IEDFs and ion flux measurement on APD: A. RF Source Pulsing- Discharge Pressure

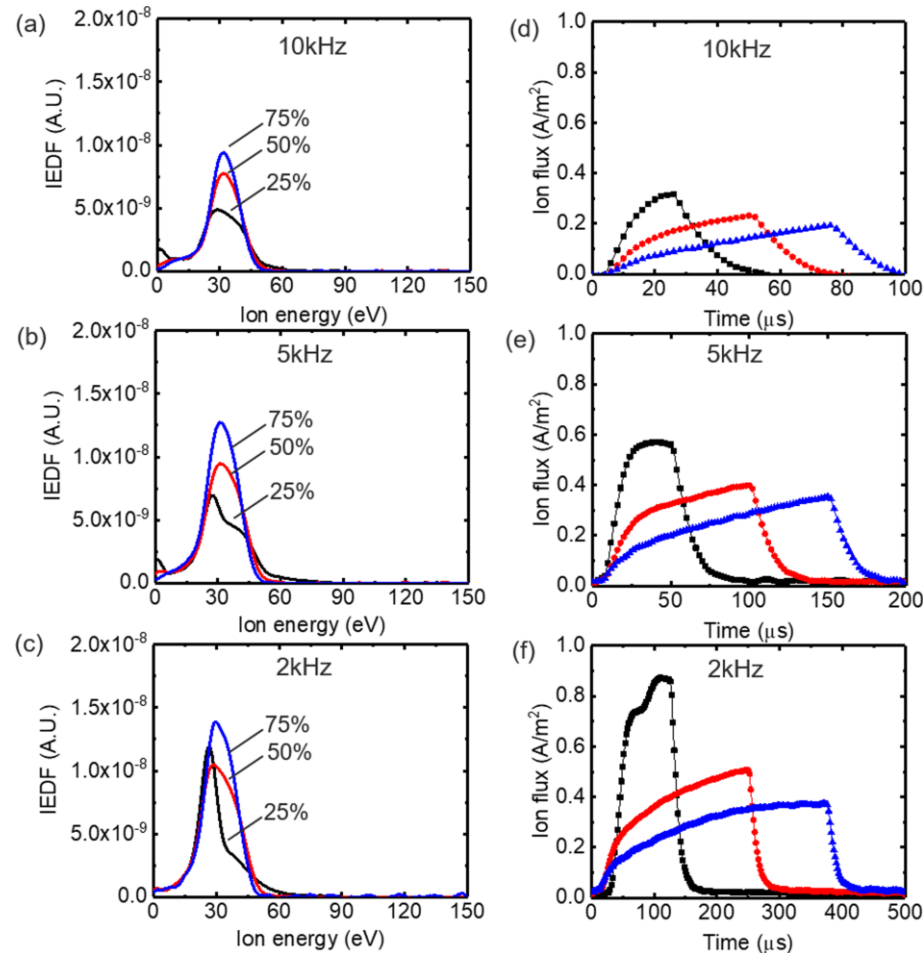


(a) Time-averaged IEDF and (b) time-resolved ion flux during one plasma pulsing period with different RF source pressures. The average RF power is 150 W, and the pulse frequency is 5 kHz. The RF source duty cycle is 25%.

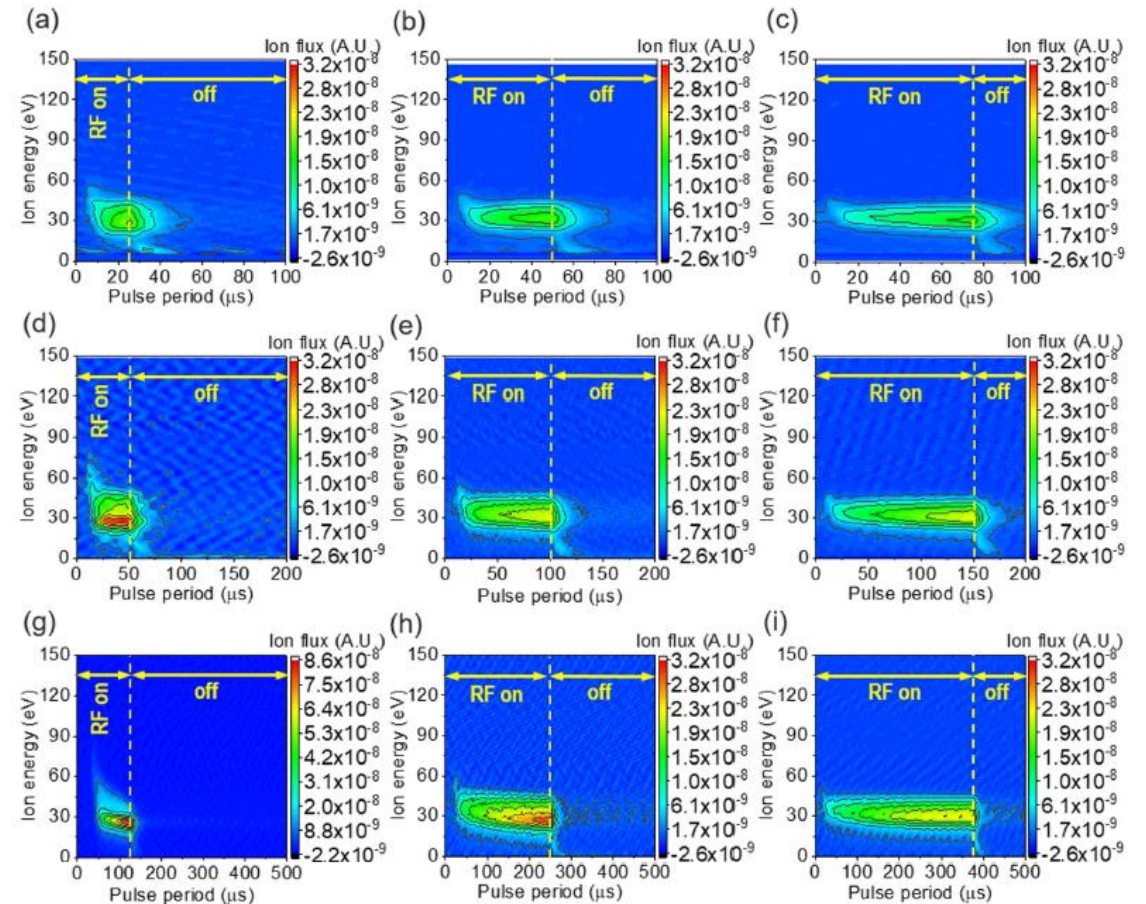


Time-resolved IEDF during one plasma pulsing period with the discharge pressure of (a) 20, (b) 40, (c) 60, and (d) 80 mTorr. The average RF power is 150 W, and the pulse frequency is 5 kHz. The RF source duty cycle is 25%.

IEDFs and ion flux measurement on APD: A. RF Source Pulsing-RF duty cycle and pulse frequency

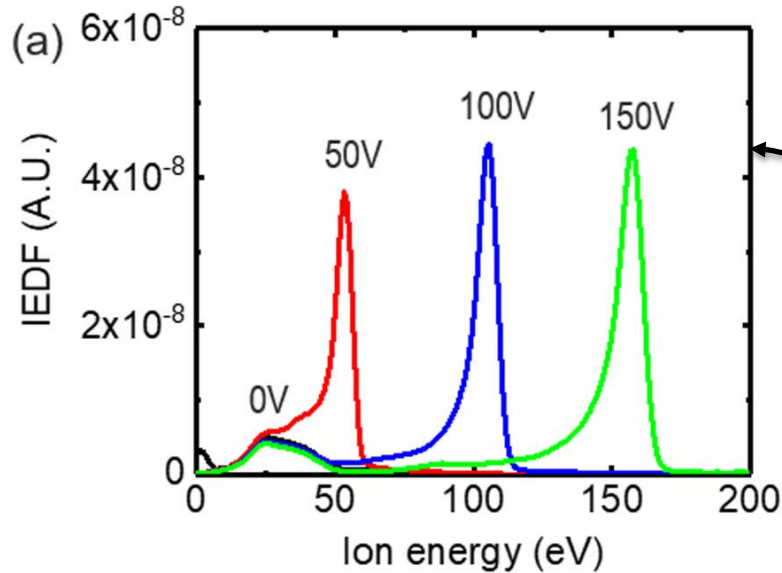


(a)–(c) Time-averaged IEDF and (d)–(f) time-resolved ion flux during one plasma pulsing period at pulse frequencies of 10, 5, and 2 kHz, respectively. The RF duty cycle in (a)–(f) varies from 25%, 50% to 75%. The discharge pressure is 20 mTorr and the averaged RF power is 150 W.

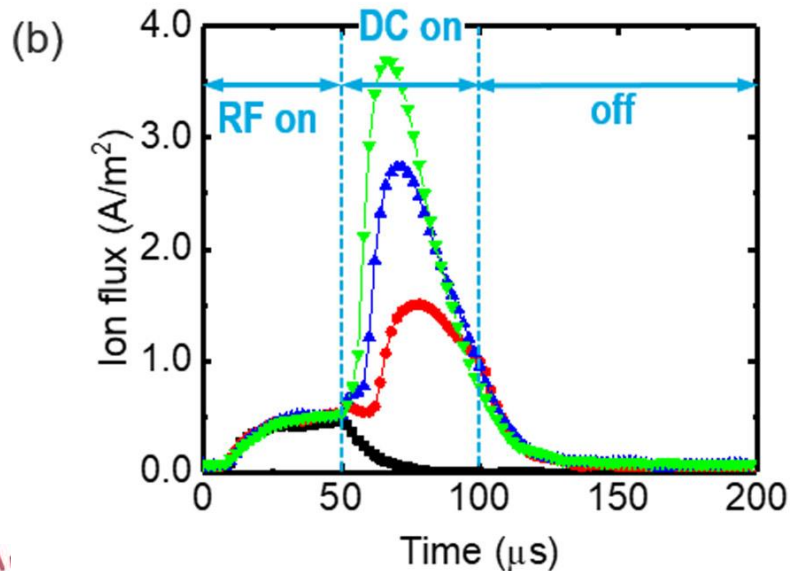


(a)–(c) Time-averaged IEDF and (d)–(f) time-resolved ion flux during one plasma pulsing period at pulse frequencies of 10, 5, and 2 kHz, respectively. The RF duty cycle in (a)–(f) varies from 25%, 50% to 75%. The discharge pressure is 20 mTorr and the averaged RF power is 150 W.

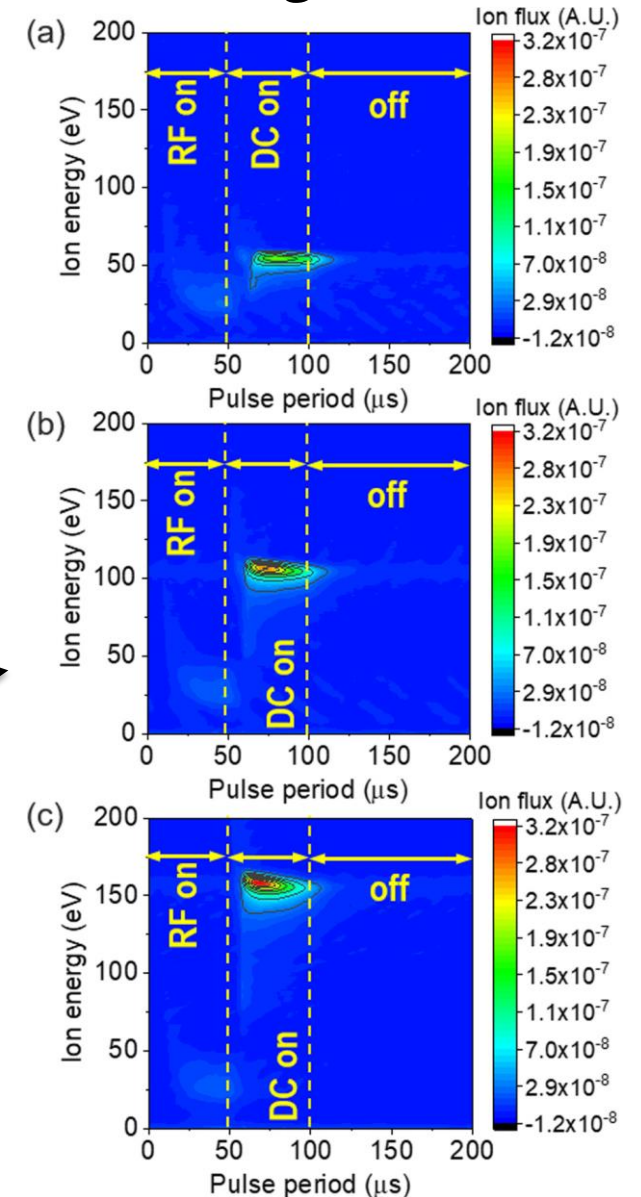
IEDFs and ion flux measurement on APD: B. Synchronized RF-DC Pulsing- DC bias voltage



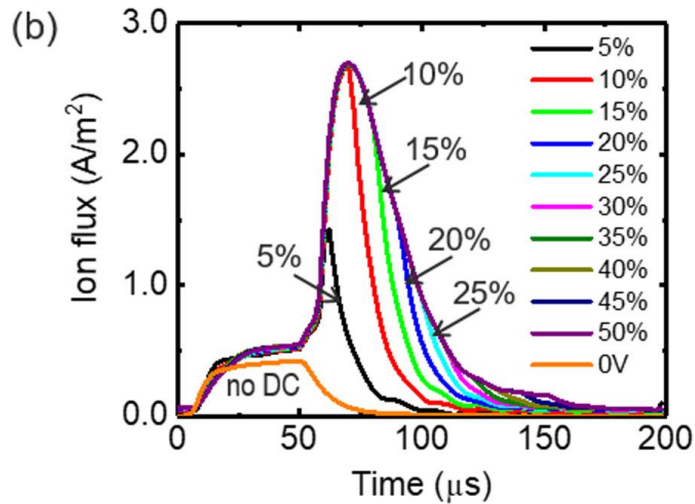
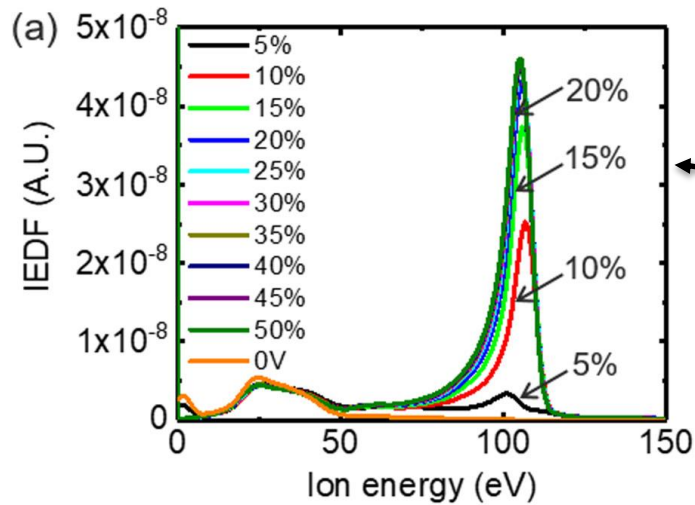
(a) Time-averaged IEDF and (b) time-resolved ion flux during one pulsing period in synchronized RF-DC pulsed plasma with applied DC voltage of 50, 100, and 150 V. The discharge pressure is 20 mTorr and the pulse frequency is 5 kHz. The averaged RF power is 150 W. Both RF and DC duty cycles are 25%. The phase lag is 50 μ s.



Time-resolved ion energy distribution during one pulsing period in synchronized RF-DC pulsed plasma with applied DC voltage of (a) 50, (b) 100, and (c) 150 V. The discharge pressure is 20 mTorr and the pulse frequency is 5 kHz. The averaged RF power is 150 W. Both RF and DC duty cycles are 25%. The phase lag is 50 μ s.

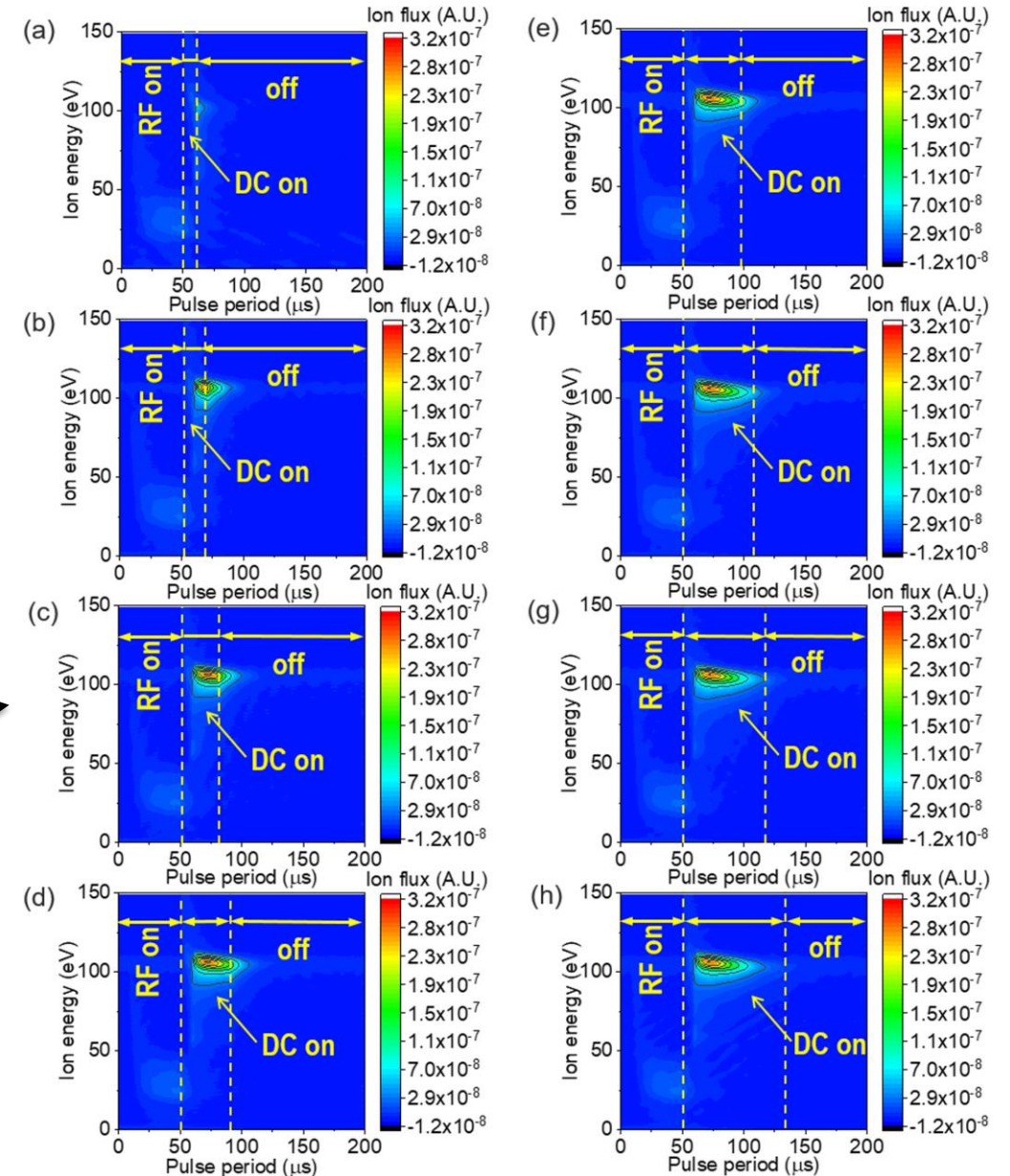


IEDFs and ion flux measurement on APD: B. Synchronized RF-DC Pulsing- DC Duty cycle

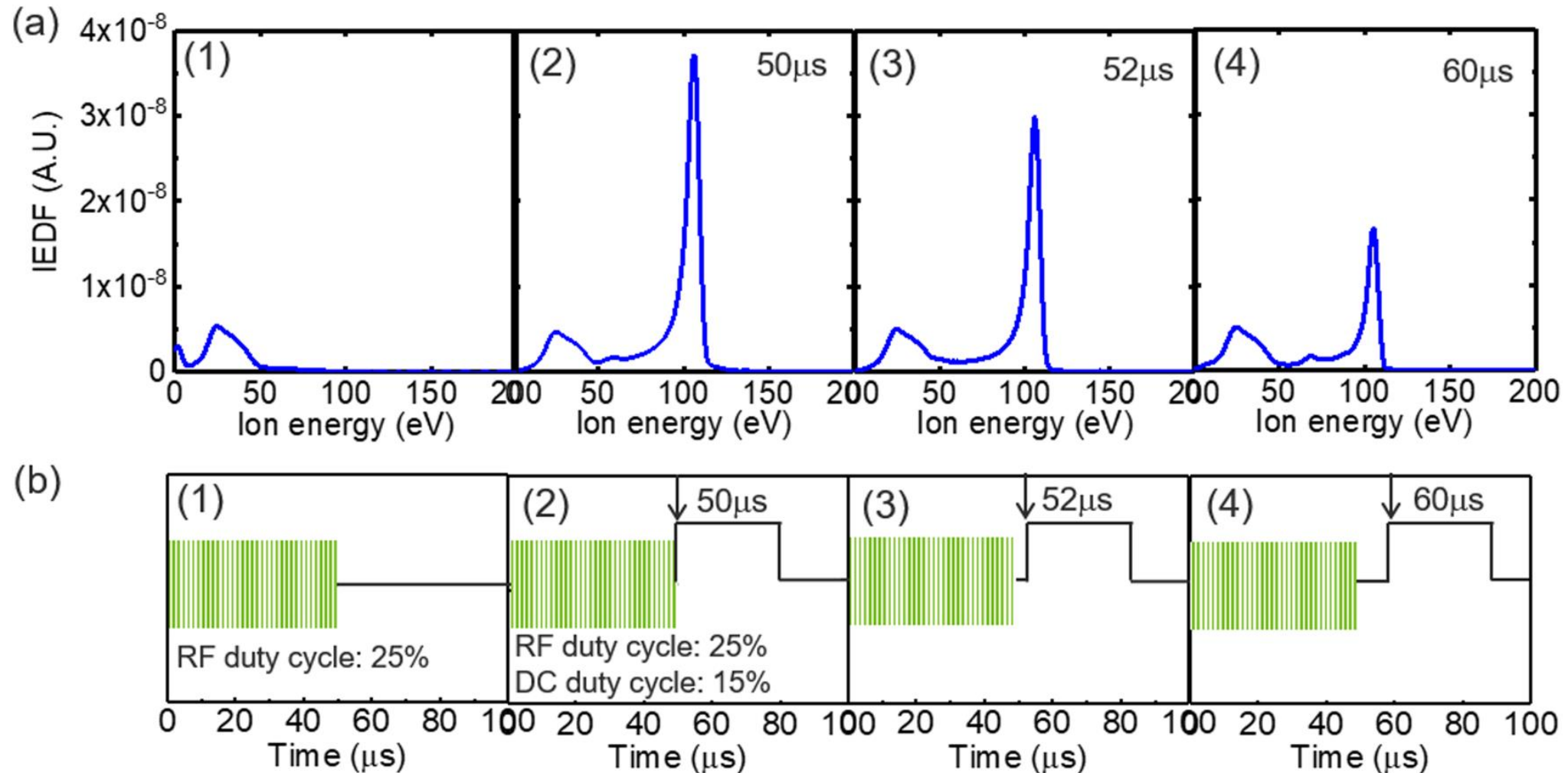


(a) Time-averaged IEDF and (b) Time-resolved ion flux in synchronized RF-DC pulsing plasma with DC duty cycle various from 5% to 50%. The pressure is 20 mTorr and the pulse frequency is 5 kHz. The averaged RF power and DC voltage are 150 W and 100 V, respectively. The phase lag is 50 μ s.

Time-resolved IEDF in synchronized RF-DC pulsing plasma with DC bias duty cycle various from (a) 5% (10 μ s) to (h) 40% (80 μ s). The discharge pressure is 20 mTorr and the pulse frequency is 5 kHz. The average RF power and DC voltage are 150W and 100 V, respectively. The phase lag is 50 μ s.

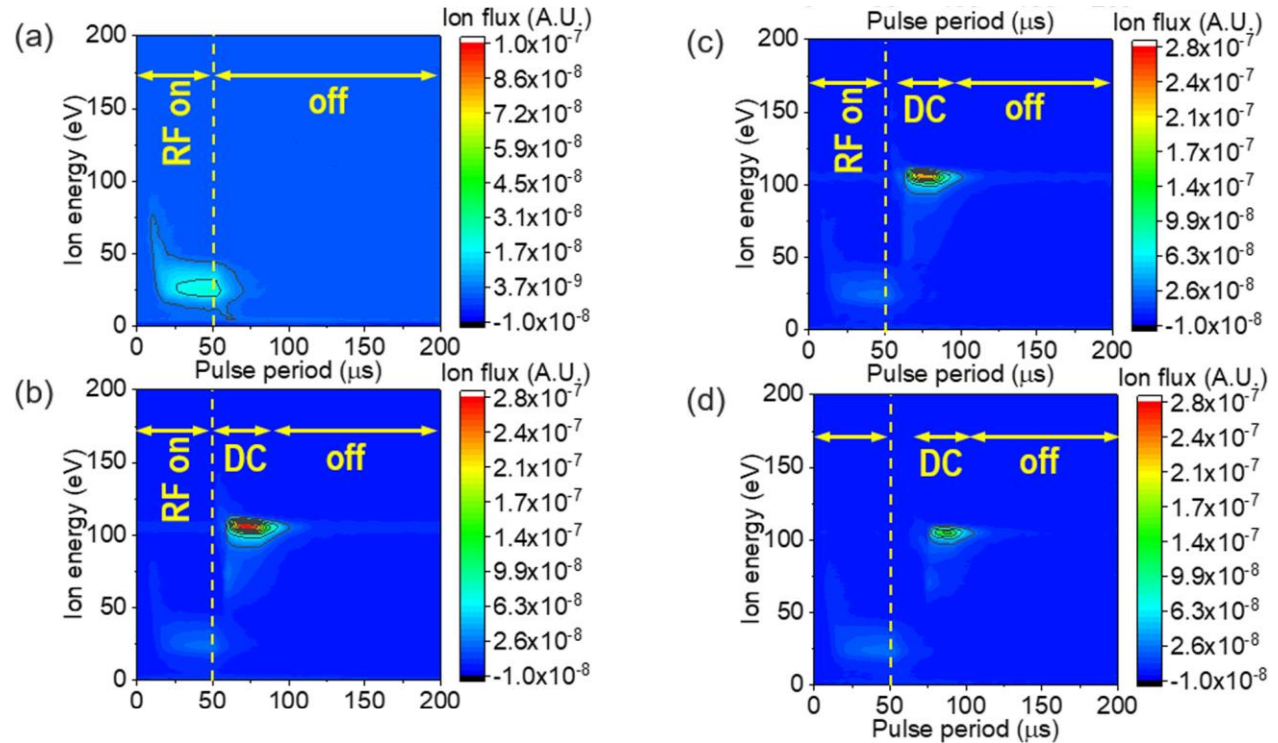
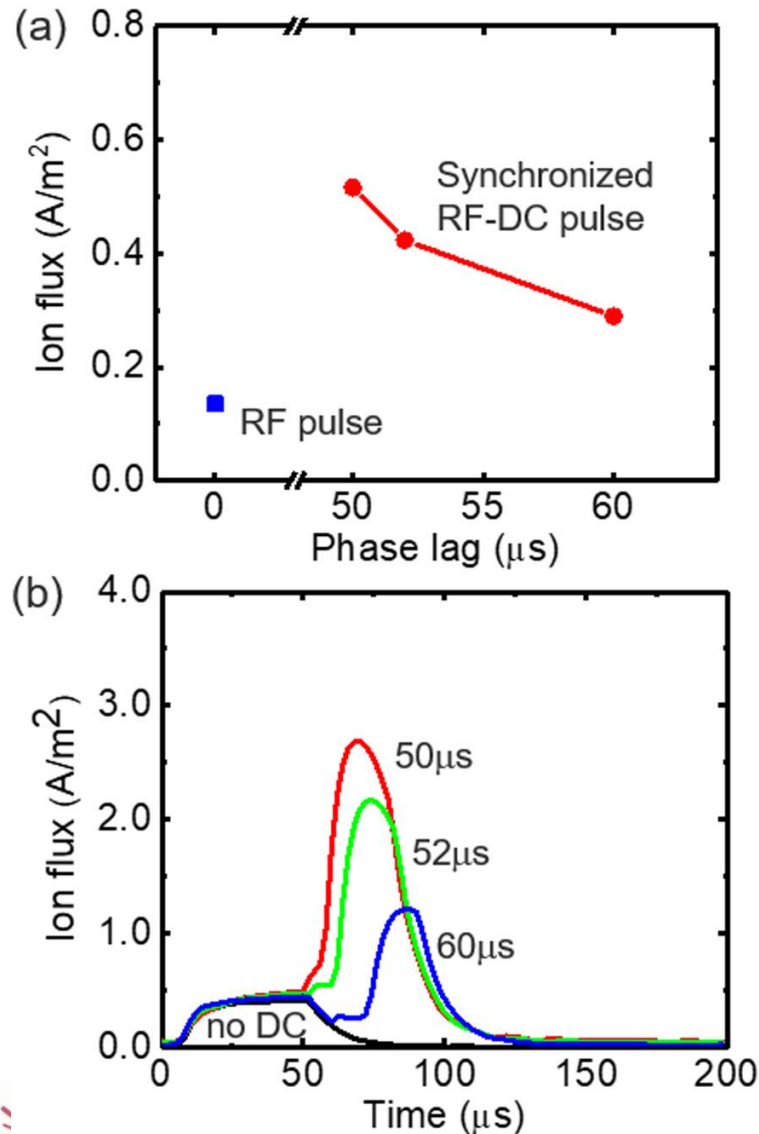


IEDFs and ion flux measurement on APD: *B. Synchronized RF-DC Pulsing- DC phase lag*



(a) (1) IED of ions extracted from RF power only; (2)–(4) IEDs of ions extracted from synchronized RF power and DC bias pulsing with different phase lags, and the corresponding phase lag from 50 to 60 μs is shown in (b) (2)–(4), respectively. The RF and DC duty cycle are 25% and 15%, respectively. The average RF power is 150 W and DC bias voltage is 100 V. The pulse frequency is 5 kHz.

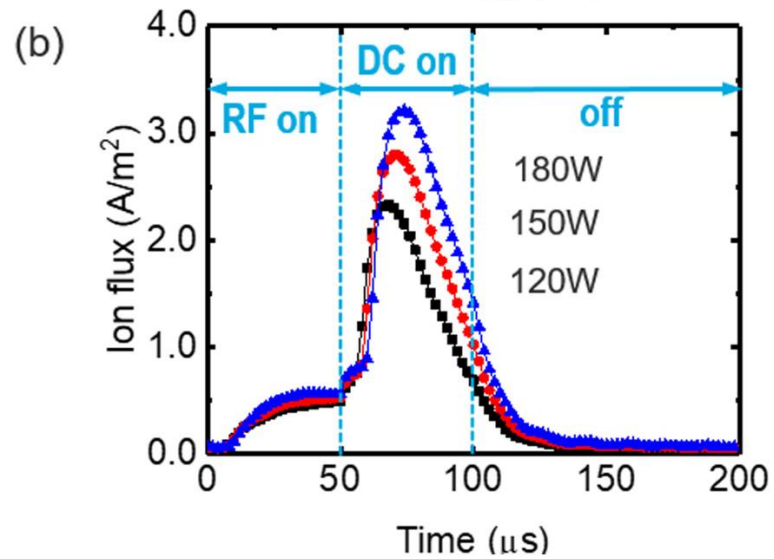
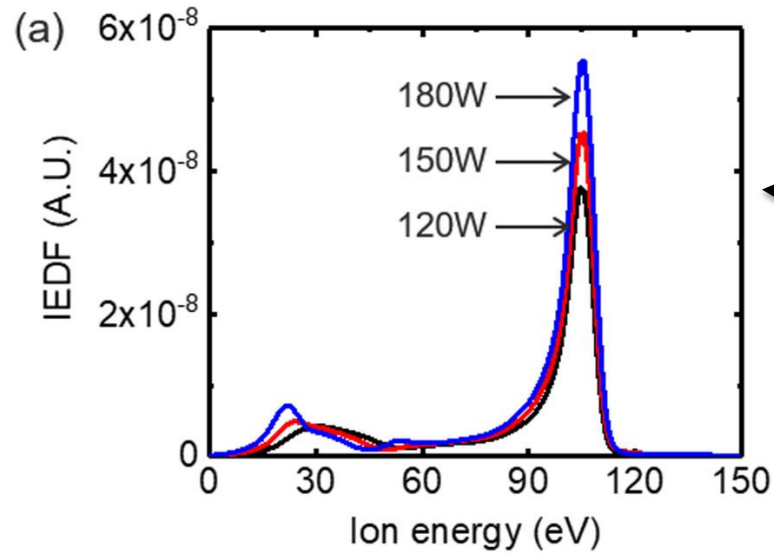
IEDFs and ion flux measurement on APD: *B. Synchronized RF-DC Pulsing- DC phase lag*



Time-resolved ion energy distribution of (a) RF pulsed plasma and (b)–(d) synchronized RF-DC pulsed plasma with different phase lags from 50 to 60 μs . The RF and DC duty cycle are 25% and 15%, respectively. The averaged RF power is 150 W, and DC bias voltage is 100 V. The pulse frequency is 5 kHz.

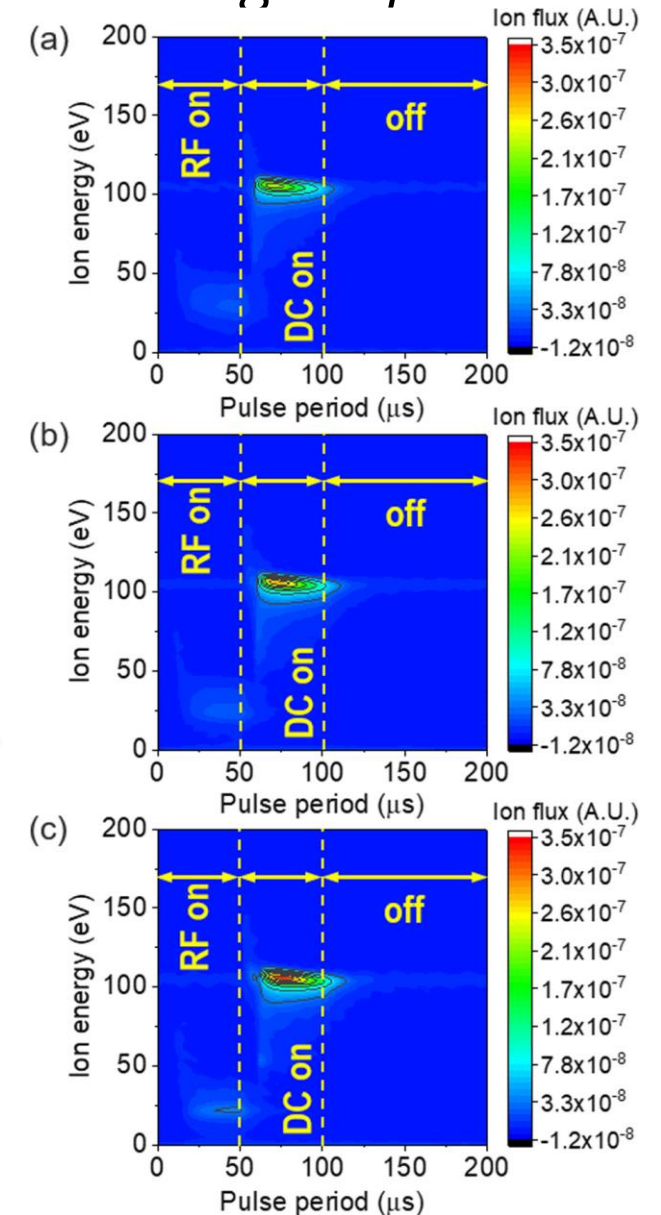
(a) Time-averaged ion flux, and (b) time-resolved ion flux in RF pulsed plasma and synchronized RF-DC pulsed plasma with various phase lags from 50 to 60 μs . The RF and DC duty cycle are 25% and 15%, respectively. The averaged RF power is 150 W, and DC bias voltage is 100 V. The pulse frequency is 5 kHz.

IEDFs and ion flux measurement on APD: *B. Synchronized RF-DC Pulsing- RF power*

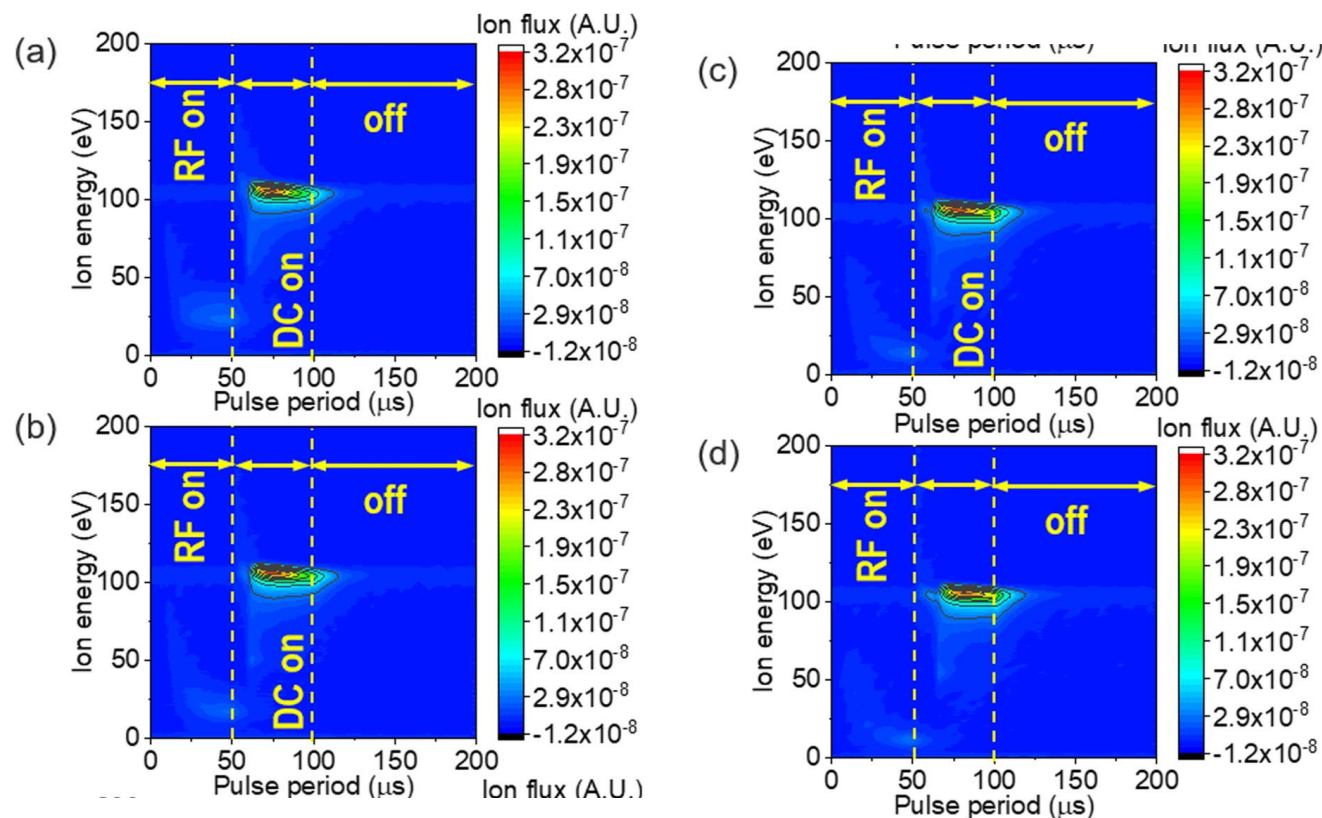
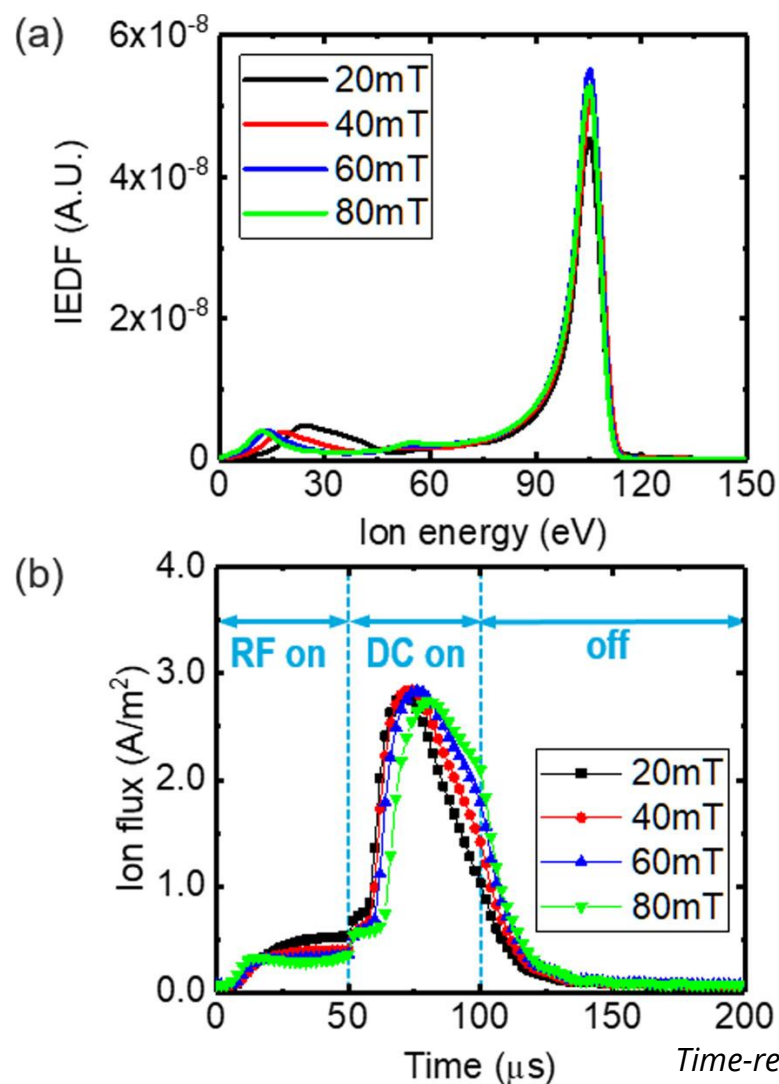


(a) Time-averaged IEDF and (b) time-resolved ion flux in synchronized RF-DC pulsed plasma with averaged RF power of 120, 150, and 180 W. The DC bias voltage is 100 V. The pressure is 20 mTorr, and the pulse frequency is 5 kHz. Both RF and DC duty cycles are 25% with a phase lag of 50 μ s.

Time-resolved IEDFs in synchronized RF-DC pulsed plasma with averaged RF power of (a) 120, (b) 150, and (c) 180W. The DC bias voltage is 100 V. The pressure is 20 mTorr, and the pulse frequency is 5 kHz. Both RF and DC duty cycles are 25% with a phase lag of 50 μ s.



IEDFs and ion flux measurement on APD: *B. Synchronized RF-DC Pulsing-Discharge pressure*



Time-resolved IEDFs in synchronized RF-DC pulsed plasma with source pressure of (a) 20, (b) 40, (c) 60, and (d) 80 mTorr. The averaged RF power is 150 W, and DC bias is 100 V. The pressure is 20 mTorr, and the pulse frequency is 5 kHz. Both RF and DC duty cycles are 25% with a phase lag of 50 μs .

Time-resolved IEDFs in synchronized RF-DC pulsed plasma with averaged RF power of (a) 120, (b) 150, and (c) 180 W. The DC bias voltage is 100 V. The pressure is 20 mTorr, and the pulse frequency is 5 kHz. Both RF and DC duty cycles are 25% with a phase lag of 50 μs .

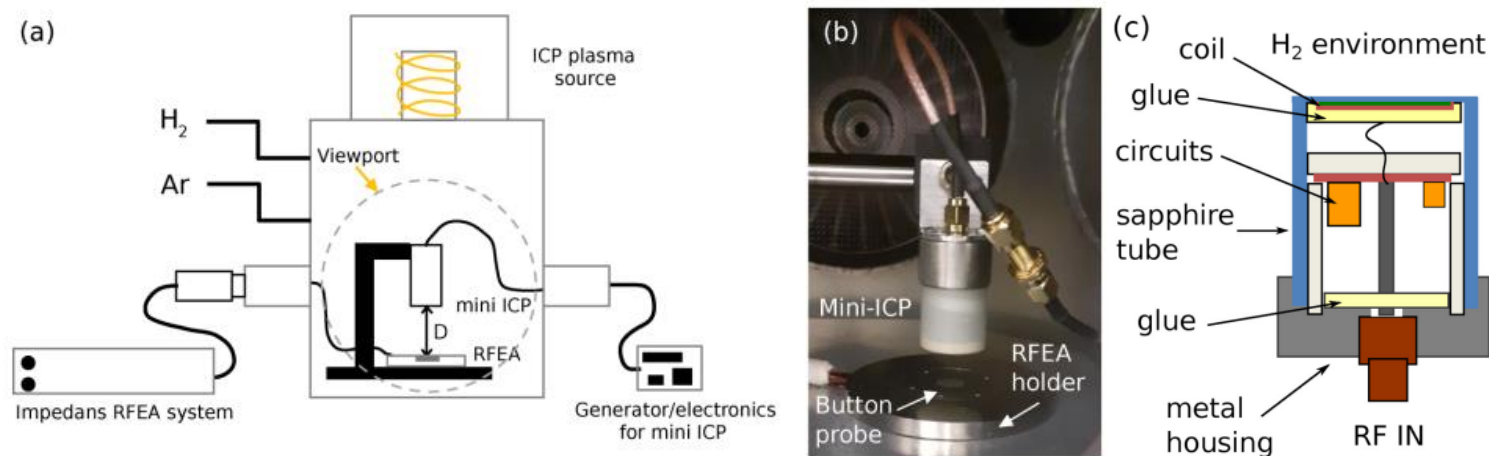
IED measurements in mini ICP Hydrogen plasma source

Miniature plasma source for in situ extreme ultraviolet lithographic scanner cleaning

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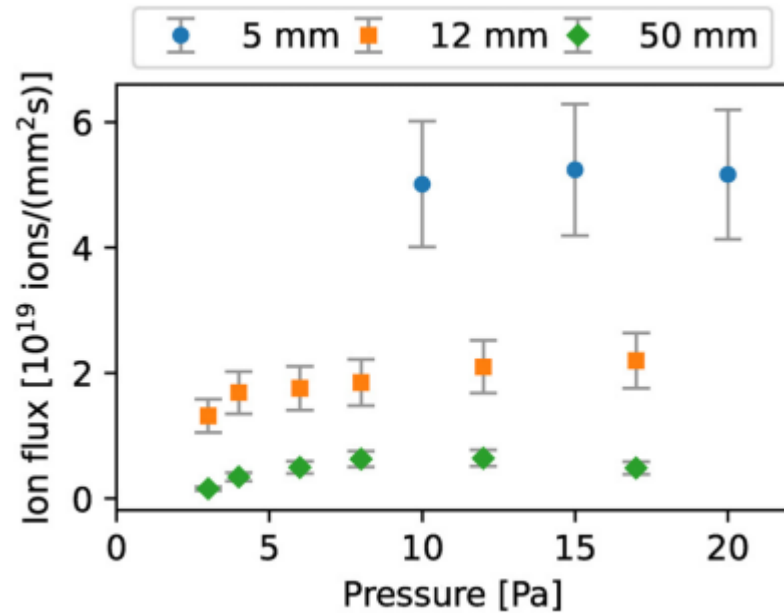
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In this work, a plasma source has been developed which has a minimized and flexible building volume to allow easy integration into various locations in the EUV lithographic scanner. The plasma-based technique create hydrogen radicals and hydrogen ions. This results in significantly improved cleaning speed while simultaneously reducing the overall thermal load

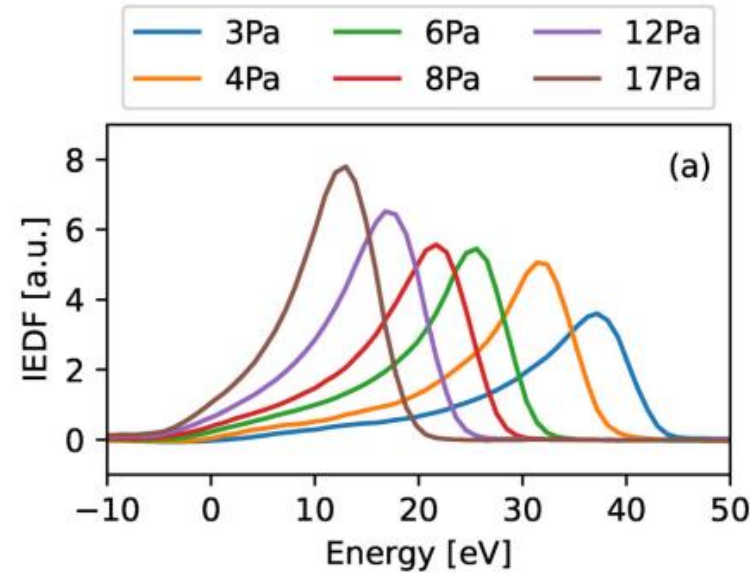


(a) Schematic of the experimental setup used for plasma characterization. The employed vacuum vessel was equipped with feedthroughs for the RFEA and mini-ICP electronics as well as with an ICP plasma source located at the top. (b) Photographs taken through the vessel viewport with the plasma on/off. (c) Schematic of mini ICP

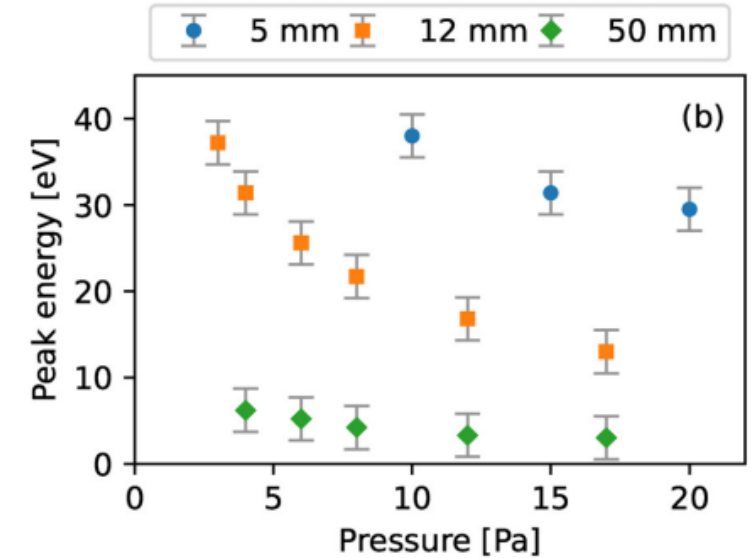
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Flux vs pressure for adjustable distance from RFEA, $D = 5, 12, \text{ and } 50$ mm. A 20% error bar is shown to indicate the typical measurement reproducibility



(a) IEDFs as measured by the RFEA for different pressures and at $D = 12$ mm. (b) Peak energy vs pressure for $D = 5, 12, \text{ and } 50$ mm. Peak energy is defined as indicated on (a) as the energy of the IEDF curve maximum.





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