Semion Commercial Applications

Measure the Ion Flux and Ion Energy incident on your substrate

https://www.impedans.com/semion_sensors
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ICP
(300 mm AMAT AdvantEdge)
Measurement of the IEDF in an AMAT-ICP system

Etching mechanisms of thin SiO$_2$ exposed to Cl$_2$ plasma

DOI: https://doi.org/10.1116/1.3622311

The objective of this paper was to investigate how a thin silicon oxide layer on silicon behaves when it is exposed to a Chlorine (Cl$_2$) plasma, in order to be able to minimise the impact of etch processes on such layers.
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
  
  DOI: https://tel.archives-ouvertes.fr/tel-00820065

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

  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.

Some example data is shown to the right

Examples of the ion energy and ion flux with power and pulsing frequency variation
The impact of the ion energy on the modified thickness and sputtering

Helium plasma modification of Si and Si$_3$N$_4$ thin films for advanced etch processes

DOI: [https://doi.org/10.1116/1.5025152](https://doi.org/10.1116/1.5025152)

The objective of this paper was to investigate the influence of He$^+$ ion bombardment on crystalline Si and amorphous Si$_3$N$_4$ substrates, for ion energies varying in the 5–250 eV range.

Some example data is shown to the right.
ICP
(AMAT Centura 300 DPS)
Ion velocity distribution functions in an Ar/O₂ Inductively Coupled Plasma

Development of innovative plasma etching processes for sub-14 nm technologies by coupling conventional lithography with the self-aligned approach by block copolymer

DOI: https://tel.archives-ouvertes.fr/tel-01285071

The objective of this thesis was to overcome some of the crucial etching challenges. In this work, it is shown that CD uniformity can be corrected by faceting the top of the patterns through plasma etching.

Some example data is shown to the right.
ICP for ALD  
(Oxford Instruments FlexAL)
Influence of oxygen ions and photons during remote plasma atomic layer deposition of metal oxide thin films

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 $\Gamma_i$ and electron density $n_e$. 
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.

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 $|V_{bias}|$. Some example data is shown to the right.
Revisiting questions regarding the operation of the RFEA

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


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

FlexAL2 reactor used for RFEA measurements
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 9 mTorr

Effects of bias power on a 600W argon plasma at 9 mTorr
Examples of measurements performed in the FlexAL reactor that show a secondary electron peak.

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).
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](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.

Substrate-tuned bias voltage, $V_{\text{sub}}$, as a function of time, and the corresponding IEDs.
ICP for ALD
(Oxford Instruments Atomfab)
Characterisation of a new low-damage remote plasma ALD system (Atomfab) for high-volume manufacturing of $\text{Al}_2\text{O}_3$ 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 Al₂O₃ for GaN devices

IFEDFs for a range of chamber pressures at 200 W and plasma powers for O₂ plasma at 94 mTorr.

Ion flux as a function of pressure for FlexAL and Atomfab sources for O₂ plasmas of 100 and 300 W.
ICP for ALE
(Oxford Instruments PlasmaPro 100 ALE)
A scalable, transfer free method to achieve horizontally individually patterned hetero-stacks

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 (ALEt) 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 ALEt process and Ion velocity distribution functions for different set points of bias voltage for (a) low bias range and (b) high bias range.*
ICP for ALE (Oxford Instruments PlasmaLab 80)
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

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.

Some example data is shown to the right.

Oxford Instruments PlasmaLab80 (PL80) reactive ion etching system – ICP source.
$\text{SF}_6$ at 3.3 Pa, modulation frequency 2 kHz, pulse duration $\tau_{\text{pulse}} = 200 \, \mu s$, 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 $U_{\text{bias}} = -95 \, \text{V}$.
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).

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

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

Pulsed ICP in SF$_6$ $\rho = 3.3$ Pa, $P_{RF} = 400$ W

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).
ICP
(Oxford Instruments Plasma Technology - PlasmaLab 100 Etcher)
Effect of the pressure and ion energy distribution: Etch profile evolution of nano-patterned silicon oxide

Balancing ion parameters and fluorocarbon chemical reactants for SiO$_2$ pattern transfer control using fluorocarbon-based atomic layer etching

DOI: https://doi.org/10.1116/1.5120414

This work presents a study of the evolution of etch profiles of nano-patterned silicon oxide using a chromium hard mask and a CHF$_3$/Ar atomic layer etching in a conventional inductively coupled plasma tool.

Some example data is shown to the right.

Cross-sectional SEM images of silicon oxide features patterned using FC-Ar ALE reported for four different pressure values, along with the IED for ~9 V DC bias, 300W ICP power, and 100 sccm Ar flow.
Atomic layer etching of SiO$_2$ with Ar and CHF$_3$ plasmas: A self-limiting process for aspect ratio independent etching

DOI: https://doi.org/10.1002/ppap.201900051

This work demonstrated that by using Ar plasma, periodic injections of CHF$_3$, and Ar ion bombardment in a conventional plasma tool, atomic layer etching (ALE) of SiO$_2$ is possible. Low energy ion bombardment is crucial for minimising the physical sputtering of SiO$_2$. This has been studied using an RFEA, and we demonstrated that the Ar ion energies are within the ALE window.

Some example data is shown to the right:

(a) Measured IED at 10 mTorr chamber pressure, 300W ICP power, and 100 sccm Ar flow.
(b) Measured electrode voltage (DC bias) and the average energy of the measured IED function as a function of the discharge power.
ICP (300 mm SEMES RIE)
The etching parameter dependence of the reactive ion etch (RIE) lag of nanometer silicon trenches using HBr/O₂ plasma

Characteristics of reactive ion etching lag in HBr/O₂ plasma etching of silicon trench for nanoscale device

DOI: http://dx.doi.org/10.7567/JJAP.53.036502

This work investigates the effects of variations in etch parameters, such as O₂ gas flow rate, substrate temperature, pressure, bias power, and source power, on the RIE lag of nanometer silicon trenches using HBr/O₂ plasma in an ICP etcher.

Some example data is shown to the right

Example of Ion Energy Distribution (IED) as a function of gas pressure, Bias power and source power.
RIE CCP (Nanomaster NRE 3500)
Control of surface ion bombardment energy using Tailored Voltage Waveforms

Excitation of Ar, O₂, and SF₆/O₂ 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](https://doi.org/10.1088/1361-6595/aaca05)

The objective of this work was to explore the use of tailored voltage waveforms as a technique to control the ion bombardment energy at a surface for various plasma compositions, namely Ar, O₂, and mixtures of SF₆+O₂. The effectiveness of this technique in controlling the ion energy has been directly demonstrated through the measurement of ion energy distribution functions (IEDFs).

Some example data is shown to the right.

Examples of RFEA measurements in Ar and SF₆/O₂ plasma for single frequency RF excitation (a), (d), peak-like waveforms (b), (e) and saw tooth-like waveforms (c), (f).
Ion Beam
(Bühler Leybold Optics Boxer Pro)
Distribution of the ion current density on stationary and rotating spherical cap substrate holders

Distribution of ion current density on a rotating spherical cap substrate during ion-assisted Deposition

DOI: https://doi.org/10.1116/1.4900541

This work presents detailed calculations of the distribution of the ion current density on stationary and rotating spherical cap substrate holders, for different positions and inclinations of the ion source.

Some example data is shown to the right:

- Ion beam characterization using RFEA ($I_d = 3\, \text{A}$, $V_d = 208\, \text{V}$, and $O_2$ flow = 16 sccm)

- Projection of the distribution of the ion current density on xy plane for a discharge current of 3A on a (a) stationary and (b) rotating substrates