Isotope Effects on Ion Flux Composition, Ar^M metastables, and Etching of Hydrocarbon films for Ar/H_2 and Ar/D_2 Plasmas

N. Fox-Lyon[(a)], A. Knoll[(a)], J. Franek[(b)], M. Koepke[(b)], V. Demidov [(c)], and G.S. Oehrlein[(a)]

(a) University of Maryland, College Park (oehrlein@umd.edu)
(b) West Virginia University (koepke@wvu.edu)
(c) Wright-Patterson Air Force Base (Vladimir.Demidov.ctr@wpafb.af.mil)

We observe important isotopic differences in plasma composition as H_2 or D_2 are added to Ar. Specifically, Ar^M density and ion flux composition depend on isotopic composition, which . enables novel tailoring of plasma surface fluxes/interactions, and presents a sensitive test/validation of models. Gas-phase impurities in plasmas cause changes in plasma properties and plasma-material interactions. We explored the consequences of adding reactive gases of different isotopes (H_2 or D_2) on the properties of an Ar low temperature plasma at low pressures. Using multiple diagnostic techniques on this inductively coupled low temperature plasma allows for real-time monitoring of plasma properties (e.g., ion composition, T_e, n_e, EEDF, and metastable densities) and plasma-material interactions (e.g. changes in material density and thickness). This setup allows one to determine and evaluate models for plasma effects when introducing gas-phase impurities into an Ar plasma and for surface of the etching material.

Adding small amounts of H_2 or D_2 to the plasma causes a large drop in plasma density as they introduce more energy loss pathways. The effects on ion composition show that ions quickly transition from inert Ar^+ ions to reactive ArX^+ and X_n^+ ions (n=1,2,3). Metastable densities also change drastically. The 420.1nm-to-419.8 nm emission intensity ratio provides a measure of the presence of argon metastables in Ar-based discharges [1] and is shown in Fig. 1. We find that the 420.1nm-to-419.8 nm emission intensity ratio when H_2 impurity is added decays faster than when D_2 is the impurity. We are currently modeling this behavior with complementary probe measurements to determine the total metastable densities in the respective plasmas [1].

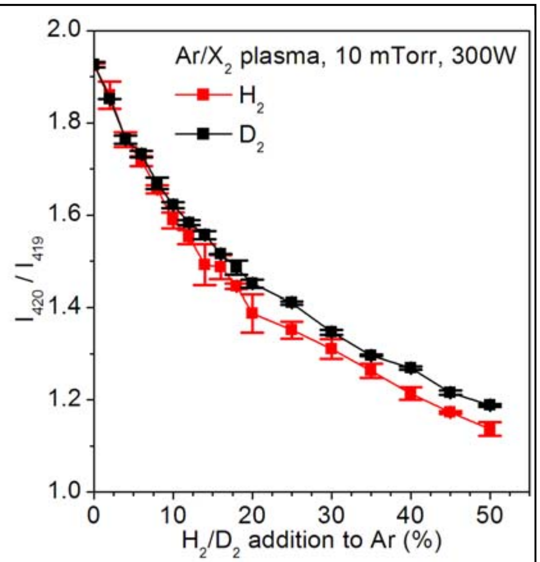


Fig. 1 – Variation of argon metastables as indicated by 420/419 nm emission intensity ratio for Ar/H_2 and Ar/D_2 discharges.

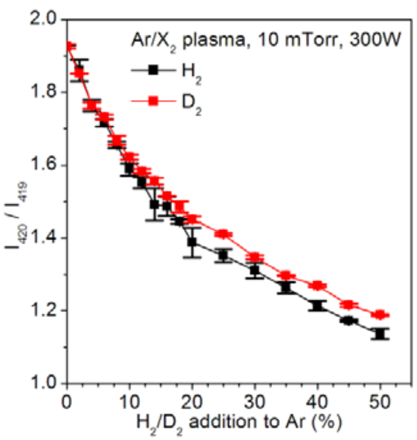
There are large differences in plasma-surface interaction between H_2 and D_2 impurities in Ar plasma. When controlling and normalizing the ion energies using a substrate bias, we find that D_2 impurities have a higher etch rate in hard amorphous hydrocarbon films. This can be explained by the faster transition to reactive ions, along with the higher average mass of the incoming ions. Along with the increased erosion rate, D_2 causes lower amounts of modification to hydrocarbon surfaces than H_2. The feedback of the etched products is higher in the D_2 case than for the H_2 case as more C and H is etched from the surface and flows into the plasma at a higher rate. C and H flowing from the surface into the Ar plasma produced similar changes as adding a small CH_4 flow.

References

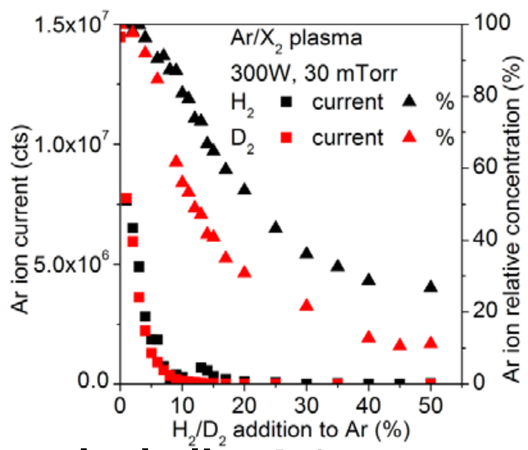
[1] S.F. Adams *et al.* Phys. Plasmas 19, 023510 (2012)

ISOTOPE EFFECTS ON Ar^+, Ar^*, AND ETCHING OF HYDROCARBON FILMS IN Ar/H_2 & Ar/D_2 PLASMAS

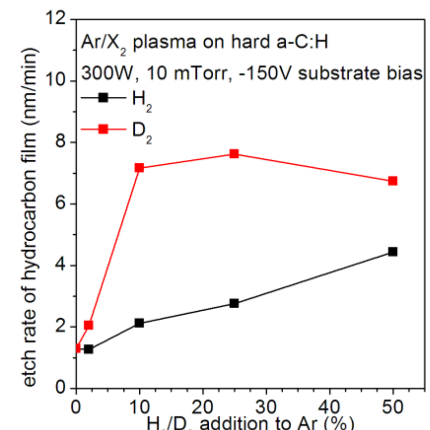
- **Multiple real-time plasma and surface diagnostics are used to characterize Ar/H_2 and Ar/D_2 plasma density/composition and interaction with hydrocarbon films.**
- **Plasma density/composition drastically change when H_2 and D_2 are added to Ar; Differences in plasma-surface effects are pronounced, with Ar/D_2 having a higher etch rate and reduced surface modification relative to Ar/H_2**
- **Isotopic differences in plasma density and composition for Ar/H_2 and Ar/D_2 (e.g., higher densities of electrons, Ar metastables and reactive ions for Ar/D_2) enable novel tailoring of plasma surface interactions and validation of models.**



• Ar metastable decays more slowly in Ar/D_2



• Though similar Ar^+ currents, D_2 has lower relative concentration



• D_2 etch rate higher

PLSC_0413 ***HIGHLIGHT***

University of Maryland 1856

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems
PSC Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics

2D Fluid Model Coupled to 1D PIC Code to obtain IEDs in Multi-frequency CCPs

E. Kawamura, M.A. Lieberman, D.B. Graves, A.J. Lichtenberg
University of California, Berkeley (kawamura@eecs.berkeley.edu)

A fast 2D hybrid fluid-analytical COMSOL-Matlab code developed to simulate multi-frequency capacitively coupled plasma (CCP) reactors has been coupled to a Matlab executable (MEX) 1D particle-in-cell (PIC) code to obtain the ion energy and angular distributions (IEDs and IADs) at the wafer of a low temperature plasma. A case for a typical multi-frequency argon CCP run on a 2.3 GHz CPU desktop computer with 8GB DRAM in less than an hour. First, a quasi-neutral bulk fluid plasma model is coupled to an analytical sheath model to obtain the particle fluxes and temperatures as well as the sheath voltage and width. Then, the MEX PIC code uses these fluid-analytical results as input to simulate the sheath region of the discharge in order to obtain the substrate IEDs and IADs. A comparison of the results from the 2D fluid-analytical bulk + 1D sheath PIC runs (red) with full (bulk + sheaths) 1D PIC simulations of a parallel-plate discharge (black) is in Fig. 1, and show good agreement.

Next, we simulated more typical axisymmetric CCP geometries. The electron density n_e and the substrate IEDs at various radii are shown in Fig. 2. The conditions are a 40 cm wafer CCP with 500 sccm, 20 mTorr argon and applied power of 1000 W at 2MHz and 500 W at 60 MHz. The electrostatic edge effect makes n_e peak near the wafer edge where there is a sharp potential gradient. The normalized wafer IEDs are fairly uniform since the sheath voltage does not vary much across the wafer. The high frequency increases the ion flux while the low frequency increases the ion anisotropy. The low frequency also tends to stabilize the discharge by increasing the sheath width. This increases the EM radial wavelength and decreases the likelihood of EM effects such as standing waves.

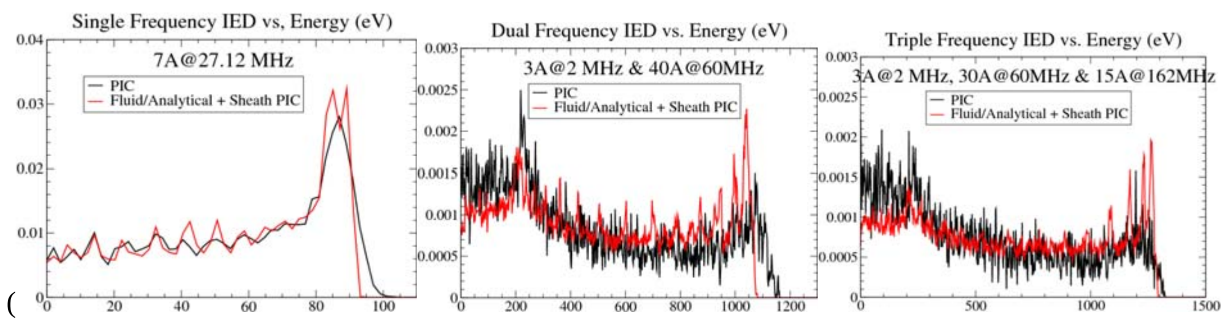


Fig. 1 – PIC results of entire discharge (black) and fluid/analytical bulk + sheath PIC results (red).

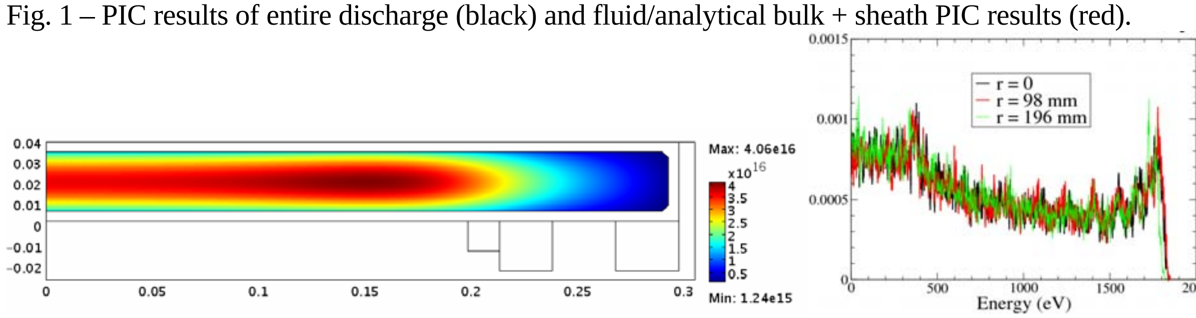


Fig. 2 – 2D fluid-analytical + sheath PIC results for n_e and IEDs at various radii for a 40cm wafer CCP.

DOE Center for Control of Plasma Kinetics

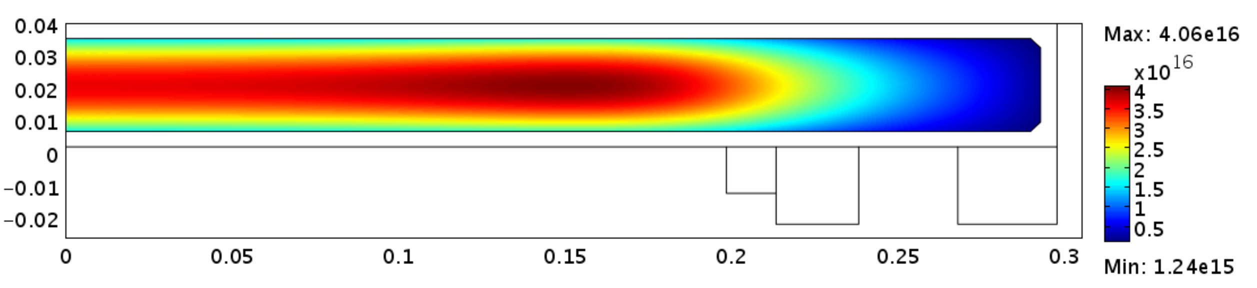
Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

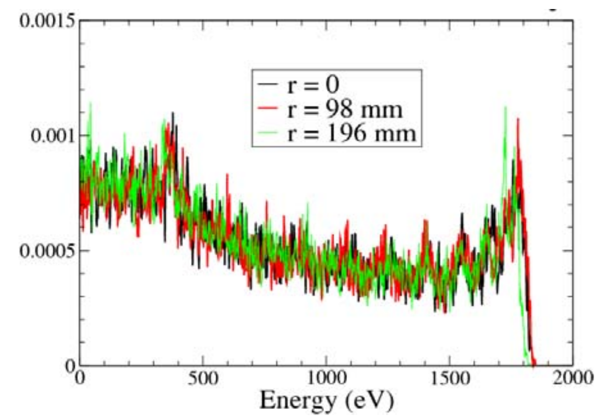
Department of Energy Plasma Science Center

2D FLUID COUPLED TO 1D PIC CODE TO OBTAIN IEDs in MULTI-FREQUENCY CCPs

- IEDs are obtained by coupling a 2D fluid-analytical code with a Matlab executable (MEX) version of a 1D particle-in-cell (PIC) code.
- A typical run takes < 1 hour on a 2.3 GHz CPU, 8GB RAM desktop computer.
- Results for a 40 cm wafer CCP with 20 mTorr, 500 sccm argon and 1000 W at 2 MHz; and 500W at 60 MHz are shown below



- Electron density n_e (m^{-3})



- Normalized IED

- Electrostatic edge effect causes n_e to peak near wafer edge.
- IEDs are fairly uniform as sheath voltage does not vary much across wafer.

HIGHLIGHT

EECS Berkeley UNIVERSITY OF CALIFORNIA

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

PSC Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics