

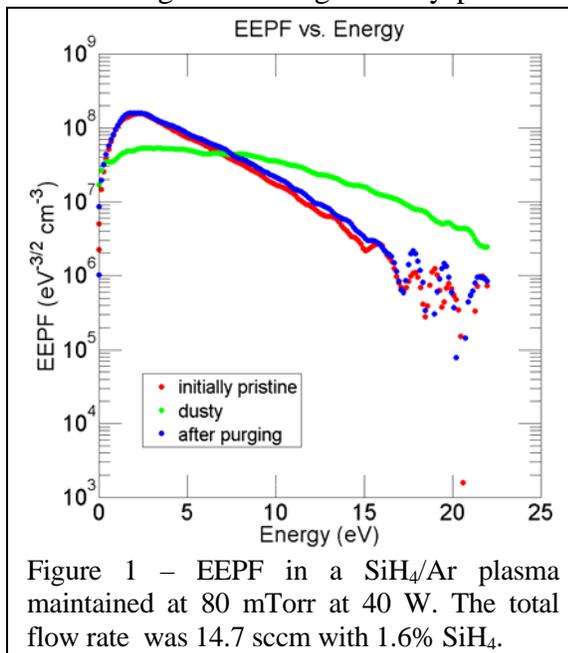
Laser Light Scattering and Electron Energy Distribution Function Measurements in a Nanodusty Plasma

Narula Bilik^(a), Yunxiang Qin^(a), Valery Godyak,^(b) Steven L. Girshick^(a),
Eray S. Aydil^(a), and Uwe R. Kortshagen^(a)

(a) University of Minnesota, aydil@umn.edu

(b) University of Michigan

Plasma synthesis of nanoparticles and nanocrystals (1-100 nm) has emerged as a viable, high throughput, solventless and potentially low cost alternative to liquid phase based synthesis methods [1]. Plasmas are being used increasingly for intentional synthesis of nanocrystals that may have applications in a wide range of electronic and optoelectronic devices including solar cells, light emitting diodes, thin film transistors and sensors. Most research to date has emphasized the materials synthesis and characterization. There are fewer studies that focus on conducting plasma diagnostics during nanoparticle synthesis. Accordingly, our goal is to use Langmuir probes and laser light scattering to study plasmas containing nanoparticles (nanodusty plasmas). Langmuir probe measurements in plasmas containing nanoparticles are particularly challenging because probes are coated rapidly. We have developed a solenoid actuator-controlled shield that exposes the probe tip to the plasma momentarily and only during the current-voltage sweep. We use Godyak's approach to obtaining the electron energy probability function (EEPF) in nanodusty plasmas [2]. Simultaneously we use laser light scattering to visualize the appearance and movement of nanoparticles in the plasma. Specifically, the measurements are conducted in a parallel-plate capacitively coupled SiH₄/Ar plasma. We demonstrated reproducible measurements of the EEPF in a SiH₄/Ar plasma containing 10-100 nm silicon nanoparticles and nanoparticle aggregates. For example, the EEPFs in a pristine Ar plasma and nanodusty argon plasma containing Si nanoparticles are compared in Fig. 1.



Langmuir probe measurements in plasmas containing nanoparticles are particularly challenging because probes are coated rapidly. We have developed a solenoid actuator-controlled shield that exposes the probe tip to the plasma momentarily and only during the current-voltage sweep. We use Godyak's approach to obtaining the electron energy probability function (EEPF) in nanodusty plasmas [2]. Simultaneously we use laser light scattering to visualize the appearance and movement of nanoparticles in the plasma. Specifically, the measurements are conducted in a parallel-plate capacitively coupled SiH₄/Ar plasma. We demonstrated reproducible measurements of the EEPF in a SiH₄/Ar plasma containing 10-100 nm silicon nanoparticles and nanoparticle aggregates. For example, the EEPFs in a pristine Ar plasma and nanodusty argon plasma containing Si nanoparticles are compared in Fig. 1.

In the presence of nanoparticles, the low energy electrons are depleted by attachment to the nanoparticles. When the nanoparticles are purged and the plasma is returned to its initially pristine state the original EEPF is recovered. The laser light scattering measurements confirm the appearance and disappearance of the nanoparticles. Time dependent measurements show that the density of low energy electrons start to decrease with the appearance of the nanoparticles. At 100 mTorr, the electron temperature rises from 4.5 eV to 5.5 eV as nanoparticle density in the plasma increases.

References

- [1] N. J. Kramer R. J. Anthony, M. Mamunuru, E. S. Aydil and U. R. Kortshagen, J. Phys. D **47**, 075202 (2014).
- [2] V. A. Godyak and I. V. Demidov, J. Phys. D **44**, 233001 (2011).

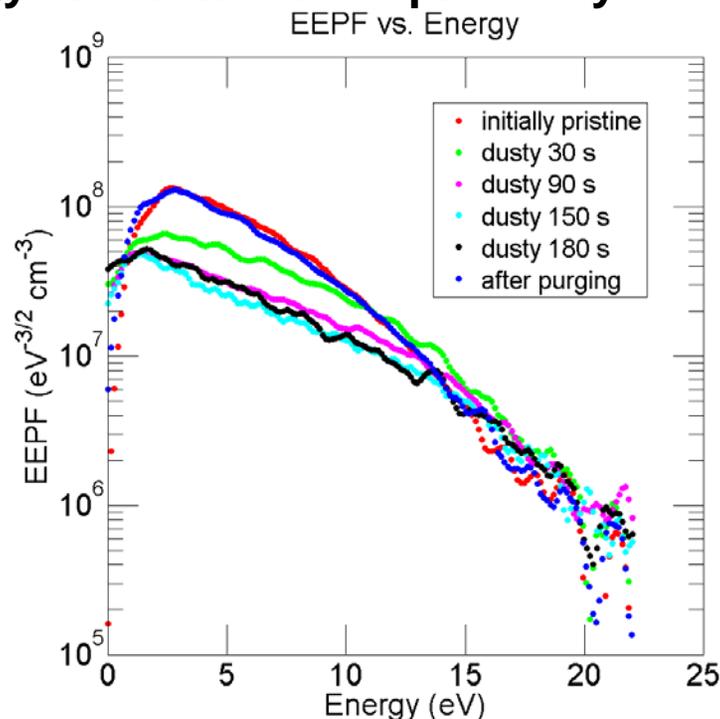
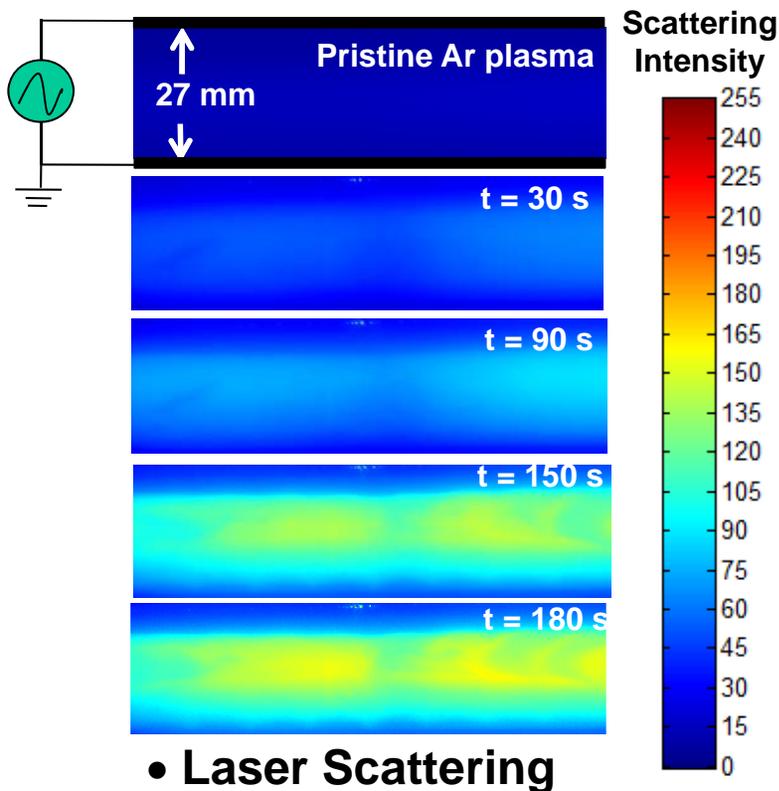
DOE Center for Control of Plasma Kinetics

Highlight



LASER LIGHT SCATTERING AND EEDF MEASUREMENTS IN A NANODUSTY PLASMA

- Using a Langmuir probe, electron energy probability functions (EEDF) are measured in a nanodusty plasma maintained between two parallel plates.
- Simultaneously, laser light scattering is used to visualize the particles.
- As particles nucleate and grow, low energy electrons are depleted by attachment to the particles.



- EEDF in a $\text{SiH}_4/\text{Ar} = 98.4/1.6$ plasma during growth of Si nanoparticles at 80 mTorr, 40 W.

Radical Species in Surface Ionization Wave Plasmas at the Liquid-Vapor Interface

Walter R. Lempert^(a) and Igor V. Adamovich^(a)

(a) Departments of Mechanical & Aerospace Engineering and Chemistry, The Ohio State University, Columbus, OH, adamovich.1@osu.edu

The kinetics of energy coupling, charge dynamics, and chemical reactions in surface ionization wave discharge plasmas remains poorly understood. In particular, experimental measurements of temperature, electric field, electron density, and species concentrations in surface discharge plasmas are difficult due to the close proximity to the surface. Kinetic modeling calculations suggest that the electron density in the near-surface plasma layer may be up to $n_e \sim 10^{14}$ – 10^{15} cm^{-3} , at the reduced electric field of $E/N \sim 10^2$ – 10^3 Td. This would result in high discharge energy loading per molecule near the surface of an evaporating liquid, with a significant fraction of input energy going to molecular dissociation. On the other hand, plasma-chemical reactions near the vapor-surface interface may occur at low temperature even at relatively high energy loadings, due to rapid evaporative cooling and the large heat capacity of the liquid.

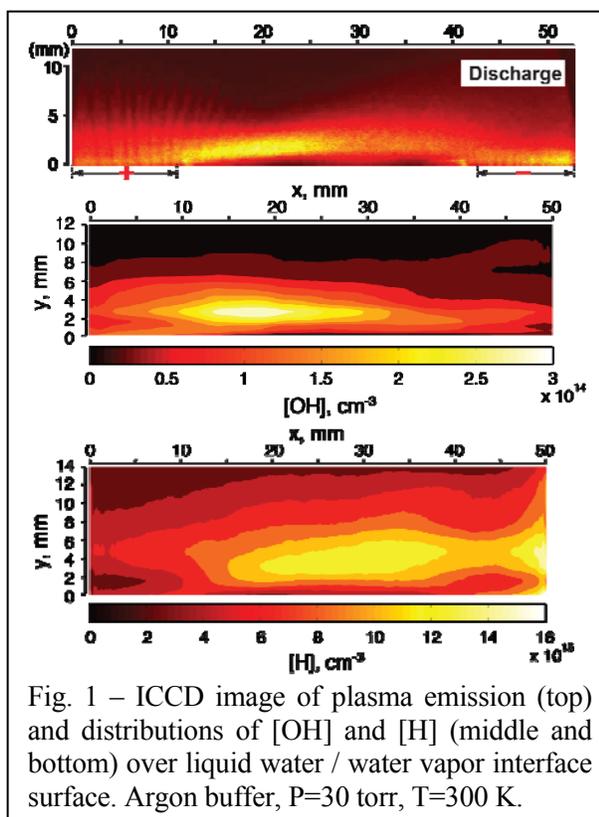


Fig. 1 – ICCD image of plasma emission (top) and distributions of [OH] and [H] (middle and bottom) over liquid water / water vapor interface surface. Argon buffer, P=30 torr, T=300 K.

For radical species number density measurements in ionization wave discharges at liquid-vapor interfaces, we used *in situ* laser diagnostics (calibrated OH LIF and calibrated H TALIF). Absolute, two-dimensional distributions of [OH] and [H] have been measured in a repetitively pulsed nanosecond discharge sustained near the liquid water / saturated water vapor interface (in an argon buffer flow), operated at the conditions when the plasma is partially lifted from the surface. ICCD images of the plasma, as well as two-dimensional, absolute [OH] and [H] distributions over the liquid surface (minimum distance from the surface ≈ 300 μm) are shown in Fig. 1. Peak [OH] and [H] for these conditions are 3×10^{14} cm^{-3} (0.03%) and 1.6×10^{16} cm^{-3} (1.6%), respectively. The H atom decay reaction, $\text{H} + \text{H} + \text{M} \rightarrow \text{H}_2 + \text{M}$, is much slower compared to the OH decay reaction, $\text{OH} + \text{OH} \rightarrow \text{H}_2\text{O} + \text{O}$. The OH distribution follows the plasma emission intensity, while H atoms diffuse / convect further away from liquid surface, generation region. The re-

sults demonstrate the capability of absolute, time- and space-resolved, *in situ* radical measurements in liquid-vapor interface plasmas (aqueous solutions or alcohols), and provide insight into kinetics of liquid-vapor interface plasma-chemical reactions. On-going measurements include NO PLIF and O, N atom TALIF.

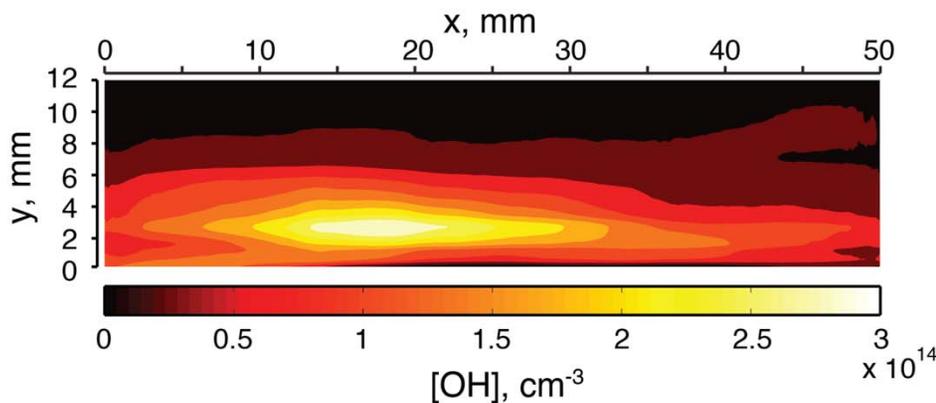
DOE Center for Control of Plasma Kinetics

Highlight

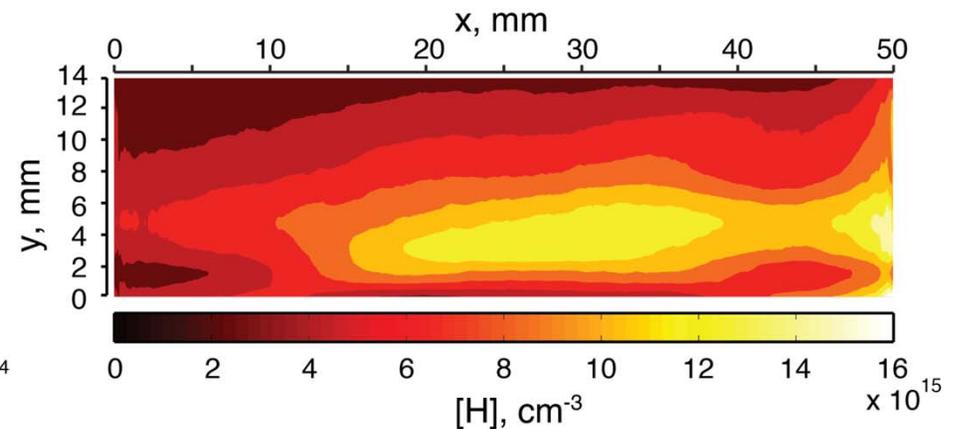


RADICAL SPECIES MEASUREMENTS IN IONIZATION WAVE PLASMAS AT LIQUID-VAPOR INTERFACE

- 2-D distributions of absolute OH and H densities measured in ns pulse, surface ionization wave plasma at liquid water / saturated water vapor interface, using line images taken by calibrated LIF and TALIF laser diagnostics.
- Peak H and OH mole fractions $\approx 1.6\%$ and $\approx 0.03\%$, H recombines very slowly, diffuses and convects with buffer Ar flow.
- Demonstrated capability of absolute, time- and space-resolved, *in situ* radical measurements (H, OH, O, NO, N) in liquid-vapor interface plasmas (aqueous solutions, alcohols).
- Insight into kinetics of liquid-vapor interface plasma chemical reactions



- [OH], liquid surface at $y=0$



- [H], flow left to right

PLSC_0614

HIGHLIGHT



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



DOE Plasma Science Center
Control of Plasma Kinetics