Characterization of Fast Ionization Wave Propagation with Optical Diagnostics

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As a continuation of our studies on fast ionization wave (FIW) discharges, optical emission and laser collision-induced fluorescence (LCIF) [1] have been used to estimate propagation velocities and effective E/N values in the front of a positive polarity (+14 kV) helium FIW.

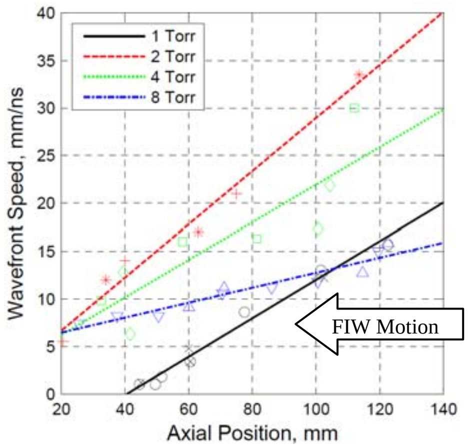


Fig. 1 – Speed of the FIW vs. pressure.

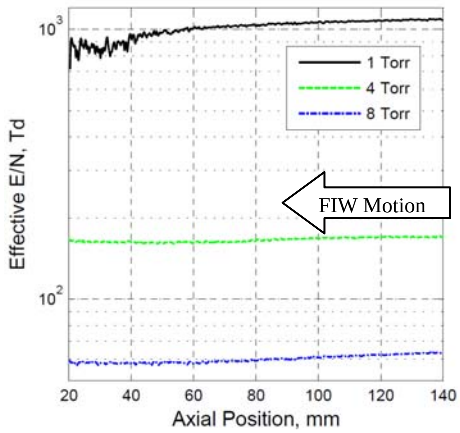


Fig. 2 – Effective E/N in the wavefront at variable pressure.

The FIW propagation speed was estimated from plasma-induced optical emission of two helium transitions (at 389 and 588 nm) from 2 to 20 ns after the discharge was initiated. 2-D images of each transition were acquired using narrow-band filters and an ICCD camera while the delay was varied. The velocity of the wave was estimated by tracking the positions corresponding to fixed values of emission intensity over time. As seen in Fig. 1, the speed decreases along the length of the tube, with a distinct dependence on pressure. Comparison with previous results (from 2-D LCIF) shows a strong correlation between wave velocities and the electron and metastable distributions produced by the FIW. At 1 Torr, the FIW speed decays to zero, corresponding to the axial position where electron and metastable production ceases; in this case, weak ionization of the background gas inefficiently neutralizes charge in the wavefront. At intermediate pressures, the speed is highest and electron production is most efficient. At higher pressures, the FIW speed is suppressed due to decreasing mobility of the back-streaming electrons.

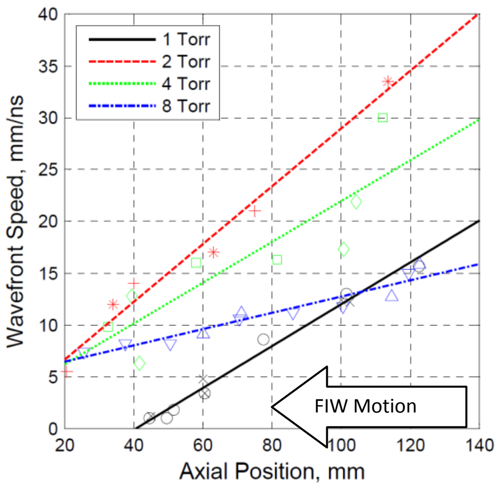
The temporal decay of electron densities in the afterglow of the FIW was used to estimate pre-pulse electron densities, and post-pulse densities were measured using 2D-LCIF. The pulse duration and the change in the densities before and after the pulse were used to estimate "effective" values of ionization rates and E/N in the wavefront, as shown in Fig. 2. In all cases, E/N decays slightly along the length of the tube, due to the residual electric field left behind the wavefront [2]. While the "effective" values of E/N provide a semi-quantitative estimate of energy deposition in the FIW, factors such as runaway electrons and photoelectrons may play a role as well. Further studies and collaboration within the DOE Plasma Science Center are currently underway to quantify the effect of these secondary processes on the propagation and spatial distributions of FIW discharges.

References

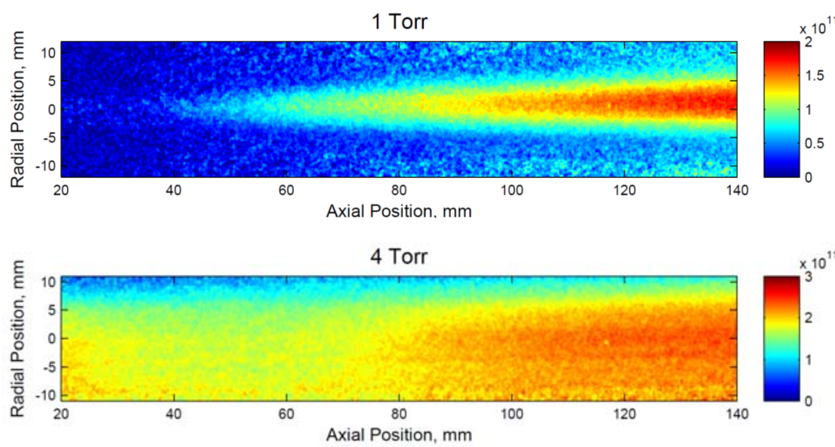
[1] E. Barnat and K. Frederickson, Plasma Sources Sci. Tech. **19**, 055015 (2010).
[2] K. Takashima *et. al*, Phys. Plasmas **18**, 083505 (2011).

CHARACTERIZATION OF FAST IONIZATION WAVE PROPAGATION WITH OPTICAL DIAGNOSTICS

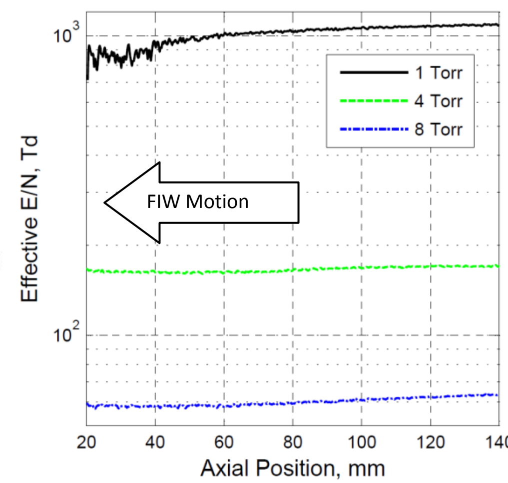
- **Fast ionization wave (FIW) speeds were estimated from plasma-induced optical emission profiles over time. Decay of wave speed correlates with electron density profiles from 2D laser collisional induced fluorescence (LCIF).**
- **Temporal decay of FIW afterglow used to estimate pre-pulse e- densities; Change in e- density due to FIW → ionization rate → E/N profiles in FIW.**
    - **Slight decay of E/N along discharge from residual E-field behind wavefront.**
- **Further studies & collaboration within DOE PSC underway to quantify contribution of non-local (runaway) electrons and/or photoelectrons in FIW.**



•FIW Speed



•Electron Density Profiles



•Effective E/N

PLSC_0512

HIGHLIGHT

Sandia National Laboratories

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

Department of Energy Plasma Science Center

DOE Plasma Science Center

Control of Plasma Kinetics

Plasma and Surface Diagnostics During Silicon Nanoparticle Synthesis in Low Pressure Silane Plasmas

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Silicon nanoparticles (~5 nm) can be synthesized in low-pressure non-thermal SiH_4/Ar plasmas. Depending on the synthesis conditions, they exhibit unique electrical and optical properties including visible luminescence across the visible range of the electromagnetic spectrum due to quantum confinement. Consequently they have potential applications ranging from light emitting diodes to solar cells. Understanding and controlling the plasma during Si nanoparticle synthesis is important because the plasma properties affect the electronic and optical properties of the particles. Using a combination of plasma and surface diagnostics (Fig. 1) we are studying the relationship between plasma properties such as the electron energy distribution function (EEDF) and spatial and temporal distributions of nanoparticles. Specifically, we use imaging of laser light scattering in combination with Langmuir probe measurements to image the nanoparticles and to measure the EEDF. The plasma diagnostics are complemented with surface diagnostics such as in situ multiple total internal reflection Fourier transform infrared (MTIR-FTIR) spectroscopy with submonolayer sensitivity. Using MTIR-FTIR we are studying the hydrogen coverage and silicon hydrides on the surfaces of these Si nanoparticles. Specifically, after synthesis, the nanoparticles are collected as a thin film on the surface of a trapezoid-shaped infrared transparent ZnSe crystal. Infrared radiation from an FTIR spectrometer is focused onto the beveled edge of the ZnSe crystal such that it is trapped in the 5 cm long ZnSe crystal and undergoes multiple total internal reflections before it emerges from the opposite bevel. During the traversal of the ZnSe crystal, the infrared radiation is attenuated at characteristics frequencies of Si-H vibrational absorptions on the Si nanoparticles. This method is sensitive to submonolayer coverage and allows the detection of SiH, SiH_2 and SiH_3 species on the nanoparticle surfaces in real time. Counter intuitively, we find that the surface hydrides on the silicon nanocrystals may be more reactive with atomic deuterium than the surface hydrides on amorphous silicon nanoparticles.

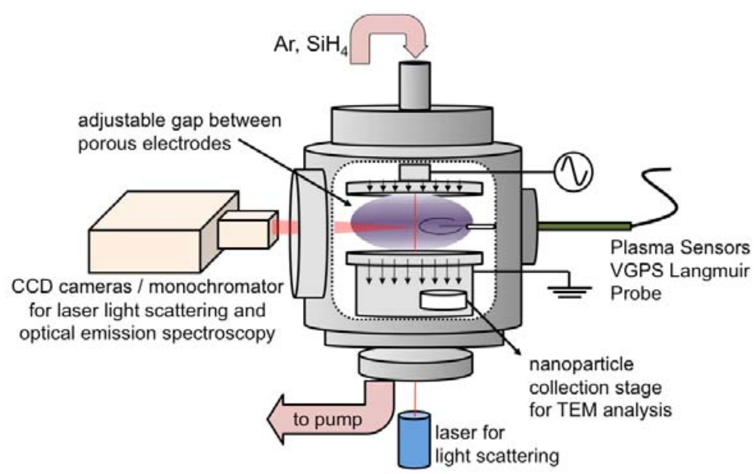
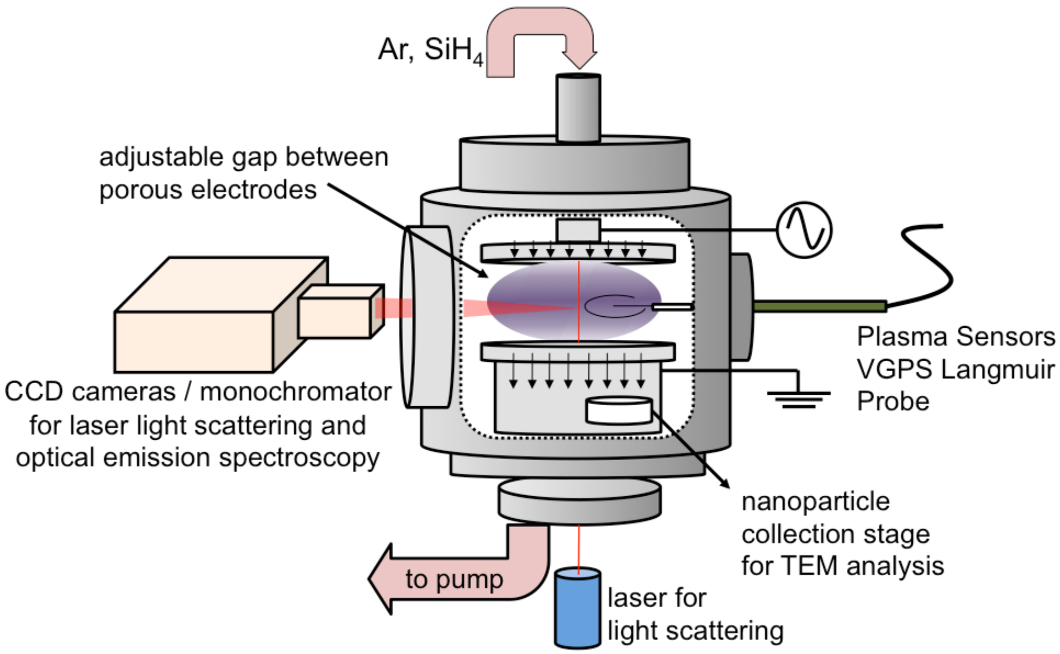
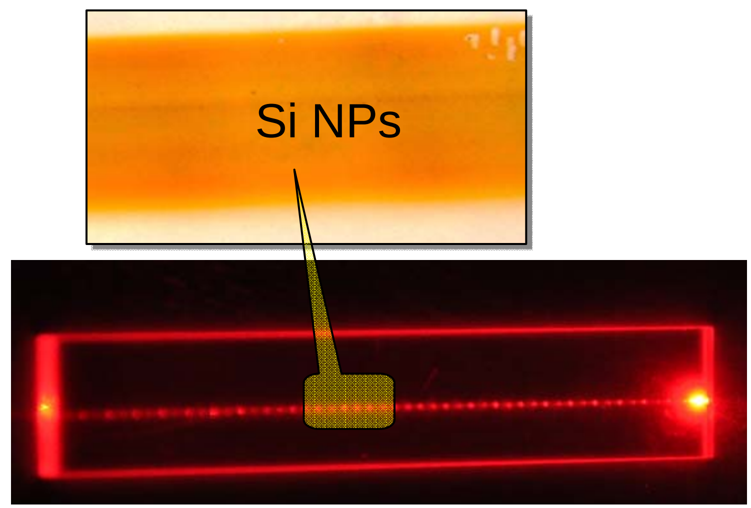


Fig. 1 – Schematic of the plasma reactor and diagnostics for studying SiH_4/Ar plasmas with Si nanoparticles.

SURFACE SPECIES ON Si NANOPARTICLES SYNTHESIZED BY CONTROLLING PLASMA PROPERTIES

- **Controlling the plasma during Si nanoparticle (NP) synthesis from SiH_4/Ar plasmas is important for applications in light emitting diodes and solar cells.**
- **Using a combination of plasma and surface diagnostics such as (left) Langmuir probes, light scattering, optical emission and (right) MTIR-FTIR spectroscopy, electron energy distribution functions, spatial and temporal distribution of NPs and H coverage on NPs are being measured.**
- **Fundamental measurements of plasma distribution functions are being correlated to NP properties to determine controllable correlations.**





PLSC_0812 **HIGHLIGHT** UNIVERSITY OF MINNESOTA

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

DOE Plasma Science Center
Control of Plasma Kinetics