Temporal and Spatial Thomson Scattering Measurements of Electron Properties of Laser-Produced Plasmas in Dry and Humid Ar

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Abstract: Laser-produced plasmas (LPPs) offer diverse applications, including nanoparticle synthesis, combustion ignition and EUV lithography. This study investigates the spatiotemporal dynamics of electron properties in Nd:YAG LPPs using laser Thomson scattering (LTS) and optical emission spectroscopy (OES) with and without water vapor addition.

1. Introduction

Laser-produced plasmas (LPPs) are highly versatile, enabling applications such as ignition of combustible mixtures [1], synthesizing nanoparticles in the gas phase [2], and generating plasma-based light sources for extreme ultraviolet (EUV) lithography [3]. Optimizing LPP efficiency necessitates understanding their spatiotemporal characteristics, particularly electron and ion dynamics, which can be probed via laser Thomson scattering (LTS). Recent advances in EUV lithography emphasize the potential of using nanosecond-pulsed Nd:YAG lasers at 1064 nm to ablate tin microdroplets for EUV applications [3]. This study presents detailed space-time resolved data of electron properties in Nd:YAG LPPs generated in dry Ar and in Ar + 3% H_2O through LTS. The latter are compared with Optical Emission spectroscopy (OES) measurements.

2. Methods

A laser-produced plasma is generated by a 50 Hz Q-switched Nd:YAG laser, 8 ns duration of about $3.5\text{x}10^{10}$ $W\cdot cm^{-2}$ intensity at 1064 nm and probed by a 50-Hz Q-switched Nd:YAG laser, 6 ns pulse duration, with $2.7\text{x}10^{9}$ $W\cdot cm^{-2}$ intensity at 532 nm. OES measurements at 656 nm (H_α) and at 486 nm (H_β) are compared with TS results. Temporal dynamics at two spatial locations (1. Core | 2. ~150 µm away) are studied from the plasma inception to ~19 ms after. Measurements are conducted in atmospheric pressure argon gas with and without the addition of 3% of water vapor.

3. Results and Discussion

Figure 1 shows the temporal dynamics of the electron number density (n_e) at the core location. n_e at the plasma core ranged from 5×10^{15} cm^{-3} to 2×10^{17} cm^{-3}, while at the side location, it varied between $4\times10^{15}cm^{-3}$ and about $7\times10^{16}cm^{-3}$. Both n_e and T_e decrease with time after plasma inception. Regarding n_e measurements, a good agreement between LTS and H_β Stark broadening measurements was observed. Absolute values n_e and T_e as well as decay dynamic trends in Ar and Ar-H_2O were found to be very similar.

4. Conclusion

This study highlights the temporal and spatial dynamics of electron properties in gas phase laser-produced plasmas.

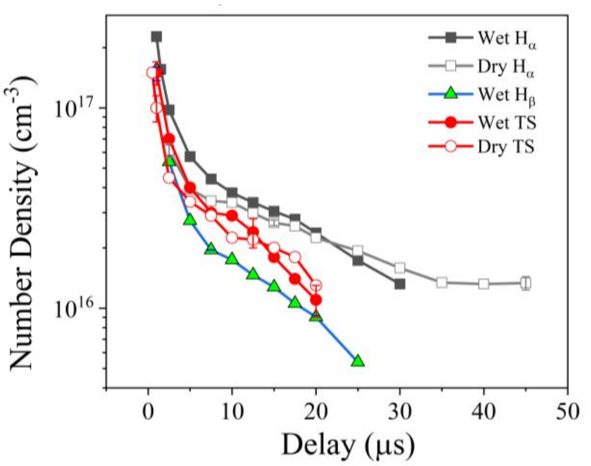

Fig. 1. TS and OES time measurement of plasma kinetics with and without water vapor electron number density.

High densities of free electrons are observed with electron temperature as high as 7 eV. The agreement between LTS and H_β Stark broadening measurements suggests the reliability of the latter OES approach compared to the H_α measurements.

Following humid and dry argon experiments, future work pertaining to EUV lithography will involve LTS measurements on a LPP on a tin-coated wire under high vacuum conditions. Additional experiments will be also performed in presence of a low pressure background gas of Ar to replicate state-of-the-art EUV debris mitigation schemes.

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