

# Impact of Environmental Conditions on the Chemistry in Laser ablation plumes

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**Abstract:** Laser-produced plasmas, or laser ablation plumes, are commonly used in a wide range of analytical, energy, and material processing applications, with their physical and chemical properties being significantly influenced by ambient environmental conditions. In this contribution, we examine the impact of the ambient environment on chemistry evolution in laser ablation plumes, focusing on reactive plasma systems including uranium (U), aluminum (Al) plumes in oxygen-rich environments, as well as tin (Sn) plasmas in hydrogen (H<sub>2</sub>) environments.

## 1. Introduction

Laser-produced plasmas (LPP) or laser ablation (LA) plumes have numerous applications, including serving as light sources for EUV lithography, surrogates for understanding high-explosion chemistry, and tools for elemental and isotopic sensing. The background gas present during LPP generation and expansion significantly affects the plasma's physical conditions, which in turn influence the plume's physical properties and chemistry [1]. Ambient gas facilitates ion deceleration/confinement, and the cooling of LPP through enhanced collisions and governs the entire LPP lifecycle, from plasma generation to particle condensation. The expansion of LA plumes into vacuum is less complex compared to their expansion in the presence of reactive gases. In such reactive environments, plasma chemistry redefines the plume's hydrodynamics and the evolution of its chemical composition [2].

Molecular species in LA plumes generally form at later times (~5 -100  $\mu$ s), predominantly due to atomic collisions and recombination when the plasma has cooled to lower temperatures ( $\leq 5000$ K). Although the LA process is extensively used across various applications, the precise timing and locations of molecular formation within the plumes are not yet fully understood. Current research efforts aim to enhance the understanding of molecular formation thermodynamics in LA plumes. Specific examples include molecular and particulate formation in uranium (U) and aluminum (Al) plumes related to high-explosion studies and tin (Sn) plasma in the presence of H<sub>2</sub> for EUV lithography applications. Here, we present our findings on the influence of the ambient environment on U, Al, and Sn plasmas.

## 2. Methods

The laser-produced plasmas are generated by focusing 1064 nm radiation from an ND:YAG laser onto the target

of interest in a vacuum chamber. The nature and pressure of the ambient conditions are varied to monitor the plume chemistry. Optical emission spectroscopy and spectrally-resolved gated imaging are employed to understand the evolution of chemistry within the plume [3].

## 3. Results and Discussion

The spectral features collected from U and Al plasmas in the presence of oxygen-containing environment showed formation of monoxide at later times of plasma evolution. The persistence of UO and AlO are greatly influenced by the oxygen partial pressure in the environment. For example, at higher oxygen partial pressures, the persistence of monoxides was reduced significantly likely due to the formation of higher oxides. Spectrally-resolved (monochromatic), fast-gated imaging results showed that molecules are primarily formed in the outer regions of plasma where lower temperature conditions exists.

The H<sub>2</sub> environment in the Sn LPP source is primarily used to mitigate optics damage in the EUV lithographic tool. However, the plasma chemistry leads to the formation of stannane molecules (SnH<sub>4</sub>). The current understanding of Sn plasma chemistry in the presence of H<sub>2</sub> and future directions will also be discussed.

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## References

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