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Unraveling the Physics of Laser-Sustained Plasma: Insights into the Influence of Laser Conditions

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The utilization of laser-sustained plasma (LSP) as a point light source has garnered attention due to its desirable characteristics, such as high light intensity, wide spectral range, and stable luminescence, which has been successfully applied in semiconductor wafer defect detection technology. LSP refers to the plasma generated by the interaction of laser and ionized gas, where the plasma can absorb energy from the laser radiation, thereby maintaining a stable high-temperature state.[1] Despite the development and practical implementation of commercial LSP-based light sources, the fundamental physical mechanisms of LSP remain unclear due to the system's complexity and susceptibility to multiple influencing factors.

Recent advancements in high-power continuous-wave (CW) laser manufacturing have expanded the range of CW lasers employed for LSP generation, including CO_2 laser (centered at ~10 μm) and fiber laser (centered at ~1 μm), among others. Existing experimental results have revealed notable differences in the conditions required for LSP generation using various types of lasers.[2] However, corresponding phenomena have not been observed in the simulation models yet, hindering the investigation of the underlying causes for these differences in temporal evolution.

In this work, we present a two-dimensional time-dependent laser-thermal-hydrodynamically coupled fluid model of LSP, which can capture the temporal evolution of LSP in the computational domain. Using Xe LSP as an example, we initially calculated the absorption coefficients, as a function of LSP temperature, for different laser types respectively. Subsequently, we obtained the temporal evolution and steady state of LSP generated by distinct lasers. Generally, the power absorption coefficients of LSP exhibit significant variations depending on the lasers' central wavelength and profile, resulting in entirely different steady-state temperature distributions of LSP. Figure 1 illustrates that the LSP absorption coefficient under conditions of lasers with central wavelength of 10.6 μm, 1070 nm, and 1080 nm, respectively. Furthermore, steady-state temperature distributions of LSP in the corresponding conditions can be seen in Figure 2. As a result, the characteristics of LSP are significantly influenced by the laser types employed for plasma sustenance.

References
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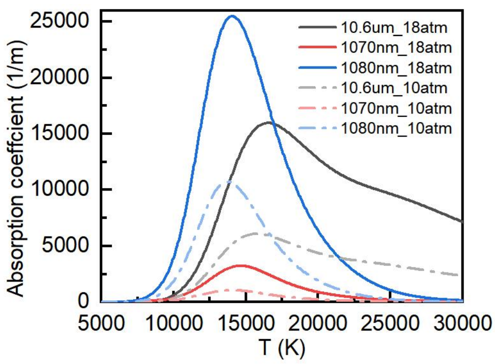

Figure 1. Absorption coefficients of Xe LSP generated by lasers whose central wavelengths are 10.6 μm, 1070 nm, and 1080 nm, respectively. The solid lines represents the absorption coefficients at the pressure of 18 atm, while the dotted lines represents the ones at 10 atm.

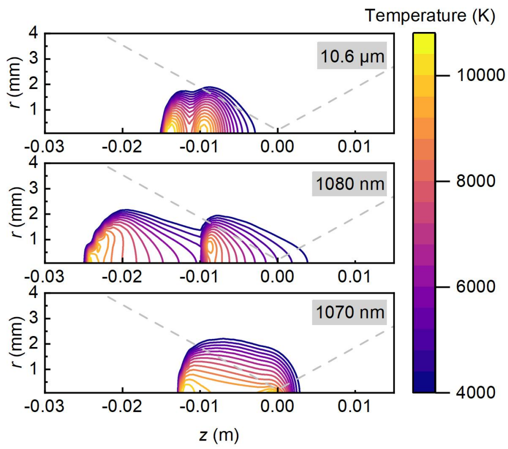

Figure 2. The steady-state temperature distributions of LSP generated by lasers whose central wavelengths are 10.6 μm, 1070 nm, and 1080 nm, respectively. Here, Xe LSP is selected, and the pressure is set as 10 atm. The dash lines represent the radius of the focused laser beam.