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Insight into the formation of the multi-core structure in laser-sustained plasmas.

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Laser-sustained plasma (LSP) has emerged as a highly promising technology due to its advantageous properties, including compact size, high energy density, and exceptional brightness. These features make LSP suitable for a wide range of applications, such as spectrochemical analysis, space propulsion, and light sources. Previous experimental studies have demonstrated the potential for LSP to exhibit a multi-core structure in terms of light intensity. In this study, we present a comprehensive investigation of the formation mechanisms and characteristics of multi-core LSP through the development of a two-dimensional multi-physics coupled model. Our model effectively simulates the spatio-temporal evolution of LSP (Xe, 5 bar) and provides valuable insights into the factors influencing the occurrence of multi-core LSP.

The formation of multi-core LSP is found to be influenced by several key factors. Firstly, higher laser power promotes the generation of multi-core structures. As the laser power increases, the energy deposition becomes more intense, resulting in higher temperatures and increased gas ionization. Secondly, slower gas flow facilitates the formation of multi-core LSP. The reduced gas flow rate allows for more efficient energy transfer and accumulation within the plasma, leading to the stabilization of multiple plasma cores. Furthermore, a larger F-number, which represents the focal length of the optical system, encourages the occurrence of multi-core LSP. The extended focal length provides a larger region for energy deposition, promoting the formation of multiple plasma cores. Lastly, stronger ignition conditions contribute to the generation of multi-core LSP. A more intense initial ignition ensures a higher temperature at the focus, allowing the remaining power of the incident laser to ignite the gas and initiate the formation of multiple plasma cores.

In our simulations, each core of the multi-core LSP is initially generated at the focal point and subsequently moves to a stable position against the direction of laser propagation. Once stable, the multi-core LSP remains positioned in front of the focus. Notably, the first core of the multi-core LSP plays a crucial role in the transformation of the incident laser from Gaussian mode to ring mode. This transformation occurs as the first core redistributes the laser energy, forming a ring-shaped structure. Consequently, the first core is sustained by central heating, while the remaining cores are primarily sustained by ring heating.

To gain a deeper understanding of the energy dynamics within the multi-core LSP, we analyze the energy terms involved. Our results indicate that the generation of each plasma core is contingent upon achieving a sufficiently high temperature at the focus. This ensures that the remaining power of the incident laser is substantial enough to ignite the surrounding gas and initiate the formation of additional plasma cores. Consequently, a stronger ignition significantly facilitates the generation of multi-core LSP structures.

In summary, our study provides valuable insights into the formation mechanisms and characteristics of multi-core LSP through the utilization of a two-dimensional multi-physics coupled model. The occurrence of multi-core LSP is influenced by several factors, including laser power, gas flow rate, F-number, and ignition conditions. Understanding these factors is crucial for optimizing the generation of multi-core LSP structures, which hold great potential for various applications. By shedding light on the spatio-temporal evolution of multi-core LSP, this research contributes to the advancement of plasma physics and enables the exploration of novel applications in fields such as spectrochemical analysis, space propulsion, and light sources.

References

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