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Simulation and Characterization of a Dual-wavelength Laser-sustained Plasma

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Laser-Sustained Plasma (LSP) is a dense plasma produced when lasers interact with ionized gases, with temperatures of tens of thousands of Kelvins. Now LSP is widely used as a mainstream light source of optical wafer inspection in the semiconductor manufacturing due to its intense radiation, broadband spectrum, and outstanding stability. In practice, there is often a desire to obtain a small, high-intensity point LSP source.

In previous studies, most LSP light sources utilize a single near-infrared laser (NIR) to sustain a high-pressure Ar or Xe plasma in an enclosed light bulb. The 1 μm-wavelength NIR continuous-wave lasers mainly heat atoms and monovalent ions in the LSP through bound-bound transitions up to 10,000 ~ 20,000 K. However, as the ionization of LSP increases during the laser heating, higher-valent ions predominate in the plasma, resulting in a significant decrease of the absorptivity for NIR lasers at regions with temperatures greater than about 20,000 K (the red line in Fig. 1(b)). As a consequence, further temperature increase in the LSP core is limited, and the size of LSP expands since the plasma boundary (~ 10,000 K) absorbs more laser power.

In our study, a new approach using dual-wavelength lasers is proposed to create smaller and hotter LSP cores. Figure 1(c)(d) shows the energy transfer processes and the setup of a dual-wavelength LSP, where a visible (VIS) laser is integrated into the NIR laser, and the VIS laser can penetrate the plasma's outer layer and is absorbed by the ions in the plasma core. As a result, the LSP core(s) have reduced lengths of ~100 μm and significantly higher temperatures of ~30,000 K.

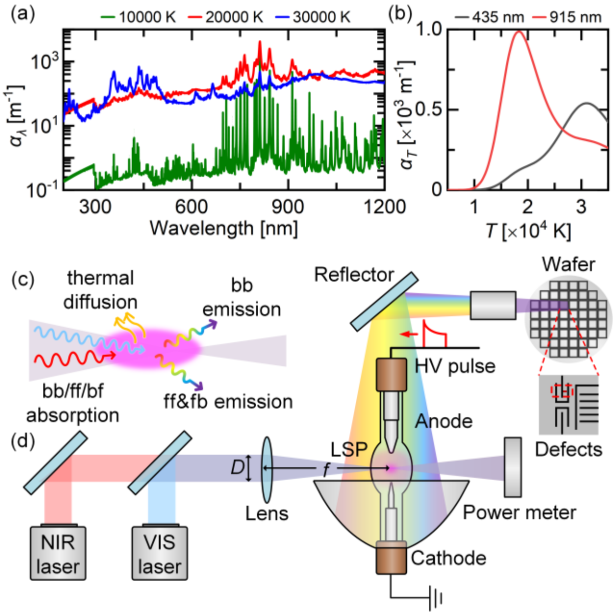

Figure 1 (a) Schematic diagram of a dual-wavelength LSP setup. (b) Absorption spectra of a 30 atm, Ar plasma at 3 temperatures. (c) Absorptivity of a 30 atm, Ar plasma versus temperature for a 915 nm laser and a 435 nm laser. (d) Main energy transfer processes of a dual-wavelength LSP, including bb/ff/bf absorption, bb/ff/fb emission, and thermal diffusion.

Here a 2D time-dependent laser-thermal-hydrodynamically coupled fluid model is established to understand the physical processes involved in the dual-wavelength LSP. Simulation results in Fig. 2 show that a high-temperature LSP core forms near the laser beam's focal point, surrounded by a lower-temperature background plasma. Furthermore, the differences between the distributions of absorbed NIR laser power density (Fig. 2(b)) and absorbed VIS laser power density (Fig. 2(d)) reveal the differences in the heating region and mechanism of the two laser beams. Compared with the NIR laser heating the whole region of LSP, the additional VIS laser is rarely absorbed at the periphery of LSP and heats the high-temperature core specially. As a consequence, the radiation power and temperature of the LSP core induced by dual-wavelength lasers is much higher than that of a single-wavelength laser LSP when comparing Fig. 2 (e)~(h). The higher temperature and smaller size of the dual-wavelength LSP light source can emit more UV radiation, and can be easier to integrated to the light-collection system.

References

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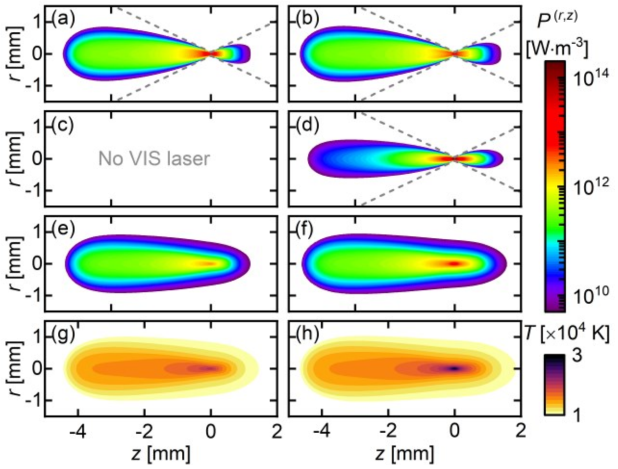

Figure 2 Absorbed NIR laser density distribution of (a) the single-wavelength LSP and (b) the dual-wavelength LSP.. Absorbed VIS laser density distribution of (c) the single-wavelength LSP, which is zero, and (d) the dual-wavelength LSP. Radiative power density distribution of (e) the single-wavelength LSP and (f) the dual-wavelength LSP. Temperature distribution of (g) the single-wavelength LSP and (h) the dual-wavelength LSP.