Supersonic Three-dimensional Sapphire Micronozzles for Laser-Plasma Wakefield Accelerators

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Abstracts: *Analysis of supersonic three-dimensional micronozzles laser-machined in a sapphire block with ultrashort femtosecond laser pulses for tailored electron beam injection into Laser Plasma Wakefield accelerators is presented. The designed sub-millimeter 3D structures are inscribed inside the transparent sapphire plate and etched with hydrofluoric acid to remove the modified material. Micronozzles will be used for investigation of the critical flow parameters like pressure, temperature and tailored longitudinal density profile formation of the gas target.*

Laser plasma wakefield particle acceleration provides a significant reduction of the accelerator length, compared to conventional RF accelerators however due to the lack of proper control over the injection of electrons into the wakefield it is difficult to produce monoenergetic accelerated electron bunches [1]. Micro-sized components in the order of tens to few hundred micrometers to control the plasma density gradient are required. The behavior of fluid flow in supersonic micronozzles of sub-millimeter-scale significantly differs from classical nozzles due to the relative importance of the viscous forces.

In this report, the analysis of several configurations of supersonic 3D converging-diverging micronozzles in the range of throat size between 30 μm and 500 μm laser-machined in a sapphire block for the controlled electron beam injection into laser plasma wakefield accelerators is presented. Based on numeric flow simulation, the critical flow parameters like density, pressure, temperature, velocity and divergence are optimized for longitudinal density profile formation of the gas target. Tailored microjets of supersonic helium and/or hydrogen gas jet will be used for the formation of a plasma channel and laser plasma wakefield electron acceleration by few-cycle femtosecond 800 nm and 1030 nm laser allowing the amplification of pulses to multi-TW power with intensity of 10^{19} W/cm^2 and propagating through the plasma with an electron density of 10^{19} cm^{-3}.

The designed sub-millimeter 3D structures are inscribed inside the transparent sapphire plate. Special kind of modification, nanogratings are formed inside sapphire due to nonlinear interaction with the laser beam. That facilitates in different etching rates between the laser-modified and the unmodified material of more than 10,000:1 in sapphire. The samples are selectively etched with hydrofluoric acid to remove the modified material, expose microchannels and hollow structures.

Proposed micronozzles are integrated with Lab-on-Chip capillary-waveguides for gas supply and control, formation of double gas jets, implementation of shocks for sharper transition in density of injected electrons into the wakefield and design of thrusters for nano-satellite applications.

[1] K. Schmid and L. Veisz, Supersonic gas jets for laser-plasma experiments, Rev. Sci. Instrum. 83, 053304 (2012)