Two-stage nozzle optimised for laser wakefield acceleration of electrons using Bessel-Gauss beams

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Emerging kilohertz laser systems, generating few-cycle laser pulses with tens of mJ of energy, provide peak intensities in the range of 10^{18}–10^{19} W/cm^2 and can be efficiently used for particle acceleration [1]. To drive the charged particles in the LWFA self-guiding bubble regime, relatively high plasma concentrations of $n=3\text{-}5\times10^{19}$ cm^{-3} and tighter focusing of the laser beam to the diameter of 3-5 µm are required. It leads to shorter acceleration distances of tens to hundreds of micrometres and results in relatively low energy and high energy spread of accelerated electrons. An axiparabola can be implemented to focus a laser beam into an extended focal line to generate a plasma waveguide to overcome diffraction or for driving a dephasing-less wakefield accelerator [2]. However, the aligning of two separate focusing mirrors for the formation of the Gauss-Bessel beam and driving beam and/or adjusting of phase for dephasing-less acceleration for few-cycle laser beams are challenging.

In this report, we propose to implement the axiparabola for the formation of a driving Gauss-Bessel beam to focus the light into the extended focal line and two-stage supersonic nozzle to optimize the injection and acceleration of electrons. The axiparabola is designed in a way to allocate the driving laser beam intensity corresponding to the laser strength parameter a_0=1.8-2.0 along the acceleration path approximately equal to the dephasing distance. The first stage of the nozzle with a diameter of 200-300 µm is used for the formation of 1% N_2+He gas jet and ionization injection of electrons. The balance of the backing pressure between the first and second nozzle stages allows to injection of electrons into the rear part of the plasma bubble and ensures the maximal acceleration distance. The second stage of the nozzle is dedicated to the LWFA acceleration of electrons in the pure He gas and defines the optimal plasma concentration for the formation of the bubble depending on the pulse energy, duration and diameter of the focused beam. The longitudinal plasma concentration profile of the second stage can be adjusted according to the experiment requirements. The two-stage nozzle was simulated using OpenFoam CFD software and manufactured from a single fused silica block using a hybrid 3D nanosecond rear-side processing and Femtosecond Laser-assisted Selective Chemical Etching (FLSE) laser machining technique [3].

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References

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