Supersonic Gas Jet Nozzle Simulation and Additive Fabrication for Direct Laser Particle Acceleration

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Direct laser acceleration (DLA) has a potential to enable significantly more compact electron accelerators for active detection of special nuclear materials (SNM). A micrometer-scale supersonic gas jet nozzle is simulated and manufactured to produce a uniform gas density profile at a specified distance from the nozzle. The gas jet is excited into a plasma state using a laser pulse to produce a plasma waveguide, which is used to accelerate electrons through DLA. Nitrogen and helium serve as the gas jet medium in simulations and experiments. Simulations for determination of the supersonic gas jet dimensions are conducted using the COMSOL multiphysics software with high Mach number fluid modeling physics. Micrometer gas jet nozzle prototype manufacturing is pursued through direct digital manufacturing techniques using stainless steel, titanium, and amorphous thermoplastic polyetherimide materials at the Pennsylvania State University (PSU) Applied Research Laboratory (ARL).

Summary of Supersonic Gas Injection System for DLA Active SNM Detection

A plasma waveguide is produced in a supersonic gas slit jet in vacuum chamber. The slit jet is mounted to the base of the vacuum chamber and connected to the pressurized static gas reservoir via a 1-mm diameter pipe. Gas at the outlet achieves uniform number density of $1.25 \times 10^{19}$ cm$^{-3}$.

The igniter and heater laser pulses are used to produce a plasma waveguide, while the pump pulse is used to accelerate electrons.

COMSOL Supersonic Gas Jet Simulation Concept

1. Slit jet nozzle concept with reservoir and gas line
2. Slit jet nozzle internal dimensions exposed
3. Nitrogen slit jet dimensions simulated in COMSOL. The critical flow configuration represents the vacuum chamber with vacuum boundary conditions on five sides (0.0133 Pa).

COMSOL Simulation Results for Supersonic Nitrogen Gas Nozzle

1. Gas density profile across the nitrogen nozzle outlet from 0 mm to 0.4 mm above the outlet. The target density profile is achieved at 0.1 mm above the outlet.
2. Gas density profile at 1 mm above the outlet.
3. Isentropic relations governing supersonic gas density and outlet area

PSU ARL CIMP-3D Resources

- EOSINT M280 manufactures metallic components using a 200 W or 400 W fiber laser. It can produce supersonic nozzles using nickel, stainless steel, or titanium. The minimum feature diameter is 0.5 mm with a minimum wall thickness of 0.15 mm.
- Stratasys Corporation FORTUS 400 mc system manufactures components in nine different types of thermoplastics including ULTEM 9085, with an obtainable accuracy of ±0.127 mm or 0.0015 mm/mm.

PSU ARL CIMP-3D ULTEM Slit Jet and Conical Nozzle Prototypes

Three nozzle designs printed in stainless steel with the EOSINT M280 through the PSU ARL. The nozzle at left is designed for helium gas using a straight pipe critical flow configuration. The center nozzle is designed for nitrogen gas, and the right nozzle is the original conical nozzle design for manufacturing technique comparison. The center and right nozzles use the de Laval critical flow configuration.

Supersonic gas conical nozzle produced in ULTEM to replicate existing stainless steel nozzle currently installed in the laboratory. This product required post-production machining to obtain the internal nozzle dimensions.

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