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Aerodynamic focusing of clusters into a high intensity and low divergence supersonic beam

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Abstract. Experiments have shown that highly intense and collimated cluster beams can be produced by a simple aerodynamic lens coupled to the nozzle of a pulsed microplasma cluster source. The mechanism of the observed cluster focusing is here presented. We discuss, as a case example, a supersonic beam of helium seeded by carbon clusters. The laminar flow of the helium-clusters mixture through a focalizing nozzle assembly has been numerically simulated and compared to the experiments. A three-dimensional steady compressible flow model has been considered for the simulation. Carbon clusters have been modeled by rigid spheres with uniform density. The trajectories of the particles are calculated during their travel through the nozzle. The simulations show that the effect of the focalizing nozzle is to divert the particles from their streamlines towards the center of the beam, thus narrowing the spatial and velocity cluster distribution. The dependence of these effects on the nozzle geometry and on the beam parameters is reproduced by the simulations in good agreement with the experimental findings.

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1 Introduction

Recently many research groups have proposed the use of cluster beam deposition for the production of nanostructured materials [1–4]. In order to make this approach competitive with other chemical and physical synthetic techniques, the development of highly intense cluster sources is a necessary requisite together with the capability of size selecting the aggregates prior to deposition while maintaining high particle fluxes [2].

The problem of generating intense particle beams with small divergence angle has been encountered by different scientific communities. Since the infancy of supersonic molecular beams it has been observed, in seeded supersonic beams, the enrichment of the beam axis with the heavy species [5–7]. These effects are known as aerodynamical focusing effects.

The importance of aerodynamical focusing has also been recognized by people working at the production and characterization of aerosols [8–13]. The study of aerosols has been substantially advanced by the development of aerodynamic focusing lenses. These devices consist of a sequence of small orifices and spacers that force the particles to be concentrated on the center beam. Since particles close to the axis experience small radial drag forces, they stay on the axis forming a narrow particle beam.

The existence of focusing effects in cluster beams has been pointed out by Miller [14] for large clusters in the subsonic region of a gas mixture flow, where a severe curvature of the streamlines characterizes nozzle expansion.

Inspired by the earlier works of supersonic expansions and exploiting the concepts developed for aerosol focusing lenses and impactors [8–13], we have recently demonstrated the production of highly intense and collimated supersonic cluster beams with a novel focalizing nozzle [15,16]. The focalizing nozzle is designed to produce a sudden turn to the flow passage. The turn can effectively divert the clusters from their original streamlines toward the nozzle axis in order to increase the cluster number density in the nozzle center and thus in the core of the supersonic jet. This result is obtained with a device characterized by reduced dimensions and ease of construction and operation [16].

In this paper we present a numerical simulation aimed at the elucidation of the mechanisms underlying the aerodynamic focusing of clusters in a supersonic expansion. The results are compared to experimental observations of the effect of the focalizing nozzle on the structure of cluster assembled films obtained by the deposition of supersonic carbon cluster beams.

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