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The Role of Gas Dynamics in Operation Conditions of a Pulsed Microplasma Cluster Source for Nanostructured Thin Films Deposition

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This study intends to explain the fluid dynamic characteristics of a Pulsed Microplasma Cluster Source (PMCS). An axially symmetric steady state simulation is performed for modeling the real-life three-dimensional unsteady flow of hypersonic helium inside our PMCS. Hypersonic helium flow is simulated using Realizable $k-\varepsilon$ turbulent model. We obtained the jet velocity, density, and pressure field inside our PMCS, for the conditions considered, and discussed them with respect to our experimental observations. We also presented a qualitative discussion on the formation-termination process of this hypersonic jet. In particular, simulation, in agreement with the experiment, indicates that the middle stage of the injection process, where the Mach disk stands close to the ablation target and at the same time the mass flow rate is relatively high, is almost the appropriate time for firing the electric discharge. We simulated the jet-electrode impingement and tracked the trajectory of the ablated carbon clusters, considered as rigid spheres, inside the PMCS. We noticed that the spatial distribution of the clusters inside PMCS is highly conserved during the free expansion of the cluster beam out of the nozzle (in the vacuum chambers) and is recognizable in the deposited carbon film. This indicates that the geometry of PMCS plays a significant role in the uniformity of the deposited film.

Keywords:

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1. INTRODUCTION

Large-scales gas-phase production of nano-particles is becoming a choice method for the synthesis of nanostructured materials.[1] In particular, Supersonic Cluster Beam Deposition (SCBD) has been proposed as a powerful technique for the growth of nanostructured thin films.[2,3] For mass production of nanostructured material assembling it is very important to understand and to control the extraction of the particles from the growth region. The pioneering work accomplished in the late fifties by Becker and Bier[4] reported on the condensation of droplets in an expanding nozzle flow in low-temperature hydrogen beams as well as in Argon and Nitrogen. Later on in the early sixties, Reis and Fenn[5] demonstrated that an accurate control on the relative concentration of clusters, within a given range of size, could be achieved in seeded supersonic beams by exploiting the aerodynamic focusing effects. Miller[6] also reported on the existence of concentration control in cluster beams in the subsonic region of a gas mixture flow. Aerodynamic effects were recognized to play an important role in the control, production and characterization of aerosols.[7–11]

More recently, it has been shown that highly intense and collimated supersonic cluster beams can be obtained with a differentially pumped apparatus equipped with a Pulsed Microplasma Cluster Sourse (PMCS)[12] and a focusing nozzle.[13,14] The aerodynamics of the focusing nozzle, in which the flow is forced through a sudden turn so that the clusters are diverted toward the nozzle axis, has been thoroughly studied by means of computational fluid dynamics simulations.[15–17] Simulation results, in agreement with experiment, revealed the importance of aerodynamic effects in controlling the spatial distribution of particulate phase in the cluster-laden supersonic flow out of PMCS. The working principle of a PMCS[12,13] consists in the ablation of a target electrode by means of a spatially confined plasma discharge. The vaporized species are

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