

Particle Formation and Dynamics in the Laser Ablation Plume

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We present a mathematical model for particle formation and dynamics in the laser ablation plume. This model is presented in a practical layout and applied to predicting the behavior of materials commonly used in the fabrication of microdevices. Additionally, we examine the intermediate intensity regime of laser ablation, in which there are multiple cooling mechanisms that can be considered important. Understanding the physics associated with the formation and flow dynamics of these particles will greatly facilitate the optimization of microfabrication production techniques involving lasers in the future.

Particles condensed out of laser ablation plume vapor coupled with those released via hydrodynamic sputtering create problems in the production of microdevices utilizing laser machining techniques. These particles can unpredictably attenuate incident laser energy in subsequent pulses. Temporal and spatial energy intensity variation caused by the remnant particles of a previous plume are currently believed to be a source of significant process variability. Additionally, vapor condensation on the workpiece itself creates quality problems, which necessitate the use of secondary cleaning processes to achieve satisfactory quality levels.

Lasers can also be used in the production of nanoscale particles. Present techniques for nanoscale particle synthesis are based on the phenomenon of homogenous nucleation in the gas phase by methods such as plasma arc, high-frequency discharge, magnetron sputtering, vaporization of materials in vacuum chamber, chemical vapor deposition, and electron beam methods. Considerable efforts are made to obtain monodispersed particles since narrow size distribution is regarded as a necessary condition for high quality nanomaterials manufacturing. Laser techniques for particle synthesis have several advantages. They allow an easy control of the evaporation process and do not require an enclosure for the evaporated substance.

The vapor ejected by laser radiation usually supercools because of its expansion and interaction with the cold ambient gas. The supercooled vapor condenses partially on the target surface and partially in the gas phase, in the form of nanoscale particles. At high laser flux density or low ambient gas pressure, a supersonic vapor flow is formed where adiabatic expansion is the predominant cooling mechanism as shown in figure 1. At lower laser flux densities, a subsonic vapor jet is created where heat conduction and diffusion mixing with an ambient gas are the predominant cooling mechanisms. Condensation conditions such as cooling rate and vapor density strongly differ at different points in the jet and, as a consequence, the size of the synthesized particles varies over more than one order of magnitude, maximum to minimum size ratio, as shown in figure 2. Previous authors generally focus on one regime or the other. In the present work, we consider both and offer useful rules, which serve to guide the process engineer in the modeling of a specific laser processing technique.

The work described herein helps to lay the foundation of basic research supporting the optimization of pulsed laser ablation processing in microfabrication as well as the production of high quality nanoparticles.

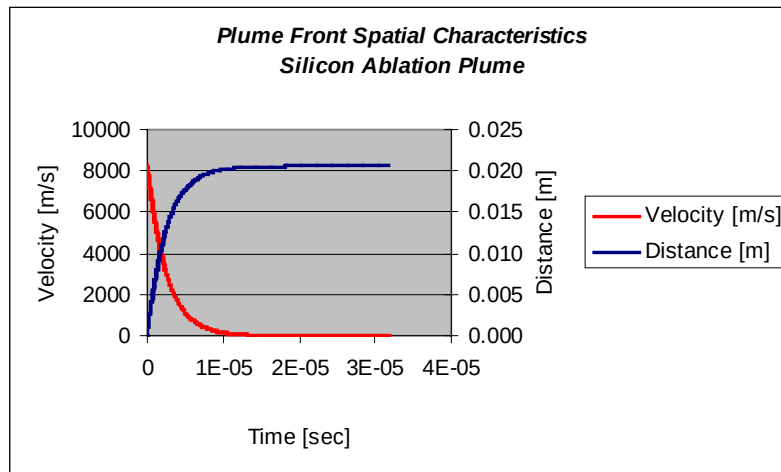


Figure 1 – Spatial Characteristics of Silicon Plume in Helium

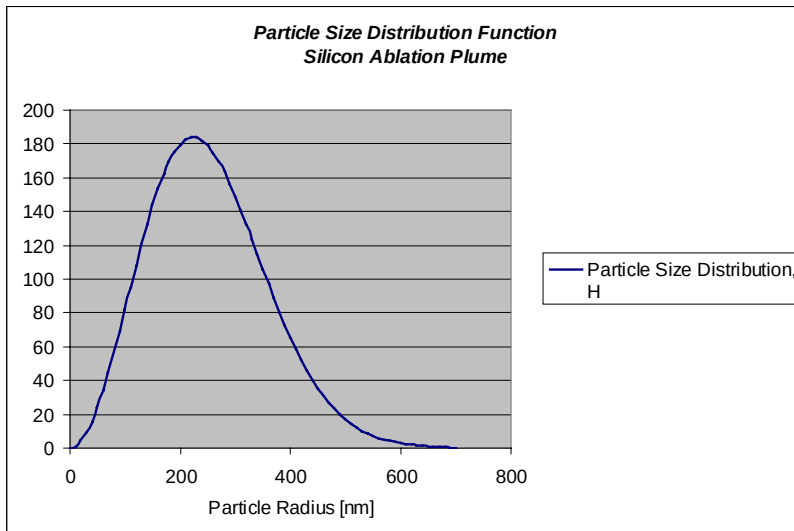


Figure 2 – Particle Size Distribution at 2ms

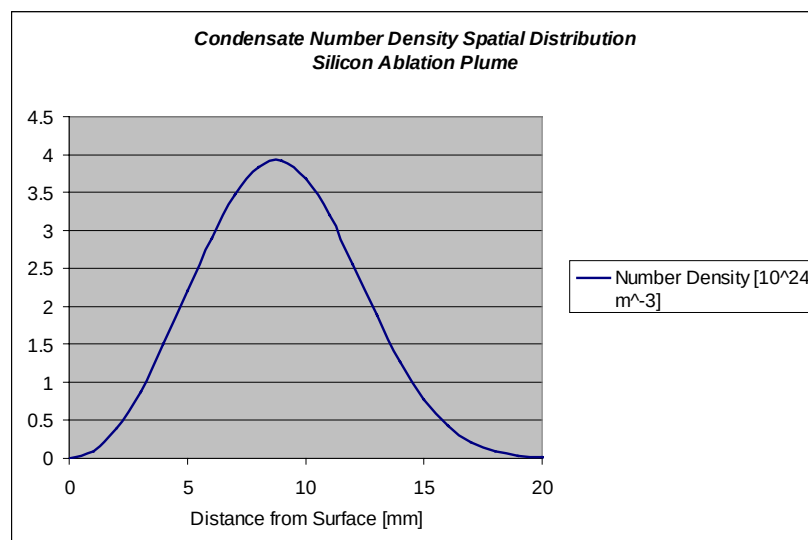


Figure 3 – Condensate Number Density Distribution at 2 ms