Generation of Aluminum Nanoparticles Using an Atmospheric Pressure Plasma Torch

John C. Weigle[1], Claudia C. Luhrs[2], C.-K. Chen[1], W. Lee Perry[1], Joseph T. Mang[1], Gabriel P. Lopez[3], and Jonathan Phillips[1,3]
[1]Los Alamos National Laboratory, Los Alamos, NM 87545. [2]Dept of Chemistry, University of Guadalajara, Guadalajara, Mexico. [3]Dept of Chemical and Nuclear Engineering, University of New Mexico, Albuquerque, NM 87131

Introduction

Many processes are being developed to produce metallic nanoparticles, spurred by the broad interest in nanostructures and their applications. Methods currently employed include metal gas evaporation, metal evaporation into a flowing gas stream, mechanical attrition, sputtering, electron beam evaporation, inverse micelle techniques, laser ablation, and decomposition of organometallic precursors. We have developed a novel method in which micron sized metal particles are sent as an aerosol through a low power, atmospheric pressure plasma torch [Weigle et al.; Phillips et al.; 2003]. The metal evaporates in the hottest region of the torch (approximately 3500 K) then nucleates and grows to form nanoparticles in the cooler regions of the plasma.

Nanometer scale aluminum particles were produced from micron scale (mean 50 μm) aluminum metal particles in an argon plasma. The plasma torch (MKS/Astex) operated at up to 1000 W. Previous studies with the same equipment demonstrated that it can be used to make a wide variety of nano- and micron-scale metals, ceramics, and composites. A three-factor, two-level designed experiment was conducted to investigate the effects of plasma gas flow rate, aerosol gas flow rate, and applied power on the shape, size, and size distribution of the final particles.

Results and Discussion

The operating conditions dramatically impacted the average size, the size distribution, and the shape of the nanoparticles. At relatively low powers or at high powers and short residence times, virtually all the particles are spherical. Under other conditions, particles had spherical heads, and virtually all had tails, some quite long. The two particle shapes are

a) b)

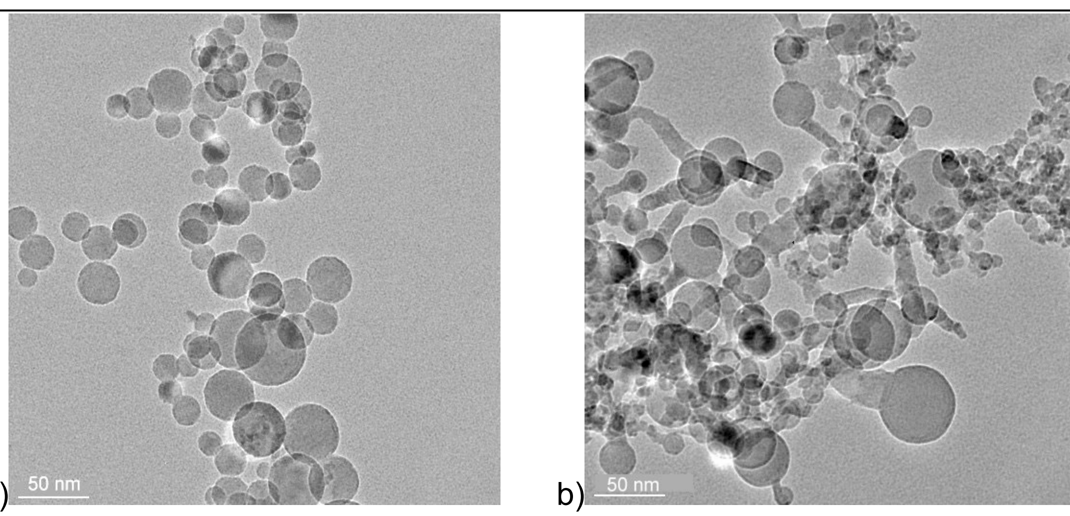

Figure 1. Different particle morphologies produced in the plasma torch. a) spherical, and b) tailed particles

illustrated in Figure 1. The tails are believed to form as a result of the solidification process of a spherical aluminum particle. That is, the particle solidifies from the outside in, resulting in a liquid core within a solid shell. Earlier work on the solidification of metals predicted that the pressure of a liquid core rises dramatically as its dimensions approach the nanometer scale. This high pressure, under the right circumstances, can cause the liquid core to break through the solid shell and form a tail.

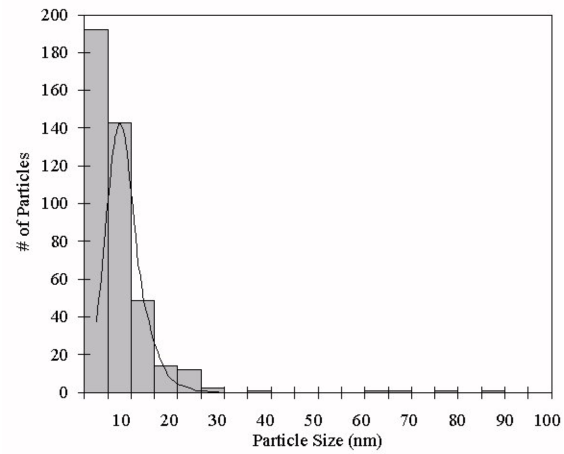

Figure 2. Particle size distribution showing a high population of small particles.

The particle size distributions also were influenced by operating conditions. The average particle size ranged from 7.4 nm to 34.2 nm. Under most conditions the size distributions were log-normal, consistent with growth by agglomeration. However, under some conditions, the population of particles above or below the mode was far too great to be consistent with a log-normal distribution. For example, the particle distributions tend to show an unusual concentration of very small particles at relatively short residence times and low aluminum feed rates. The distributions tend to show an unusual concentration of large particles at relatively long residence times and high aluminum feed rates. One example of a distribution that deviates from log-normal behavior is shown in Figure 2. These deviations from a log-normal size distribution were confirmed with SAXS.

On the basis of the data collected, some simple models of the mechanism of nanoparticle formation were postulated. Relative particle velocities were estimated to equal the thermal velocity of the particles, and we investigated the importance of kinetic energy, particle charging, and viscous drag. Our analysis indicated that viscous forces only play a role in particle collisions over a limited particle size range, roughly between 1 and 10 μm. Electrostatic forces may explain the presence of the small particle branch. Alternatively, these particles may form as a result of continuous surface ablation and particle nucleation. The model was not sufficient to explain the presence of the excess large particles seen in some distributions, suggesting that other mechanisms such as turbulent mixing are involved.

References

Weigle, J. C., C. C. Luhrs, C. K. Chen, W. L. Perry, J. T. Mang, M. B. Nemer, G. P. Lopez, and J. Phillips, “Generation of Aluminum Nanoparticles Using an Atmospheric Pressure Plasma Torch,” *J. Phys. Chem. B.*, submitted.

Phillips, J., W. L. Perry, and W. Kroenke, “Method for Producing Metallic Nanoparticles,” *U.S. Patent Application*, 20030196513, (2003).