Plasma Torch Production of Novel Materials

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SUMMARY-

A low power (<1200 W), atmospheric pressure, microwave plasma torch has been successfully employed to make a host of potentially useful materials including supported metal catalysts, micron scale spherical ceramics (solid and hollow), spherical nano-metal and nano-oxide particles, core-shell complex nano-oxide particles, single wall carbon nano-tubes and spherical boron nitride (2004 R & D 100 winner). Each material fabrication required understanding of the mechanism of formation in order to arrange the plasma system. For example, in order to generate spherical BN particles in a nitrogen plasma was employed. This generated a sufficient N atom concentration to prevent decomposition, and allowed the heretofore theoretical melting temperature of BN to be reached. Nanotube formation required the generation of a unique precursor stream. Specifically, carbon monoxide was flowed over a bed of iron to create a mixed gas that upon decomposition in the plasma created the gas composition that empirical evidence indicates leads to the formation of nanotubes: nanoscale iron particles and C-atoms. Some general considerations of particle formation in a plasma, such as the influence of particle charging, as well as some (surprising) results of spectroscopic studies of the influence of particles on atmospheric pressure plasmas will be presented as well.

BACKGROUND

The underlying premise of all work with the atmospheric pressure torch performed in our laboratory in the last decade is that it not only is the torch a new method for making materials, but it can be employed to make unique materials. Successes include development of a method for making crystalline BN in spherical form (1) and a novel form of single wall carbon nanotubes: 'threads'(2). There is also evidence that supported metal catalysts produced in the plasma torch have unique catalytic properties (3).

The present work, an extension of earlier reports, is a demonstration that ceramic oxides that can be prepared using the atmospheric pressure plasma torch. Forms generated include truly spherical nano-alumina oxide particles, hollow micron scale spheres and 'core shell' nano-particles.

EXPERIMENTAL

Using a simple aerosol generator, either dry particulate aerosols or aqueous aerosols containing dissolved reagents are sent through a low power (<1500 W) atmospheric pressure plasma torch configured in a fashion similar to one described in the literature (4). For example, nanoalumina spheres are made from a dry aerosol of argon containing a very low concentration of solid particles, average size 50 microns, of elemental aluminum. Other significant details include: i) power is maintained at between 700 and 1000 W, ii) net solid flow rates of no more than 3 grams/hour in order to insure all input powder was converted to nanoparticles. iii) a net gas mixture when the aerosol flow is added to the 'plasma gas' flow (4) of approximately one percent oxygen with the balance argon and iv) and total gas flows of the order of 1 liter STP/minute. Essentially, the method is very similar to one described elsewhere (5,6) for producing nano metallic particles, with only one major change: the addition of a small amount of oxygen to the plasma gas.

RESULTS/DISCUSSION

As shown in Figure 1 nanoparticles of truly spherical alumina can be readily generated, at rates of more than 3 grams/hour, using the plasma torch method. It is also possible to change the phase of the alumina by modification of the plasma operating conditions (Figure 2).

Using a starting aerosol containing a mixture of cation precursors it is possible to make some truly unique hollow, micron sized particles (Figure 3), as well as core-shell structures (Figure 4) in which one cation dominates the surface layer and the core is dominantly the other.

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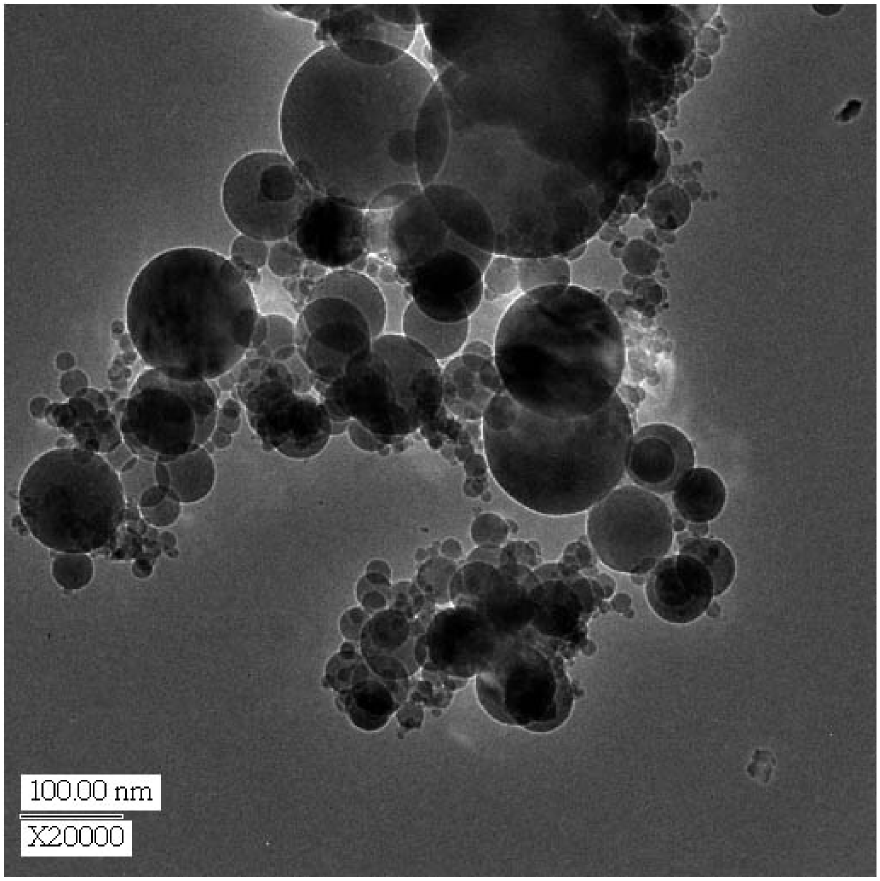

Figure 1- Highly spherical nano alumina particles against the holey carbon grid.

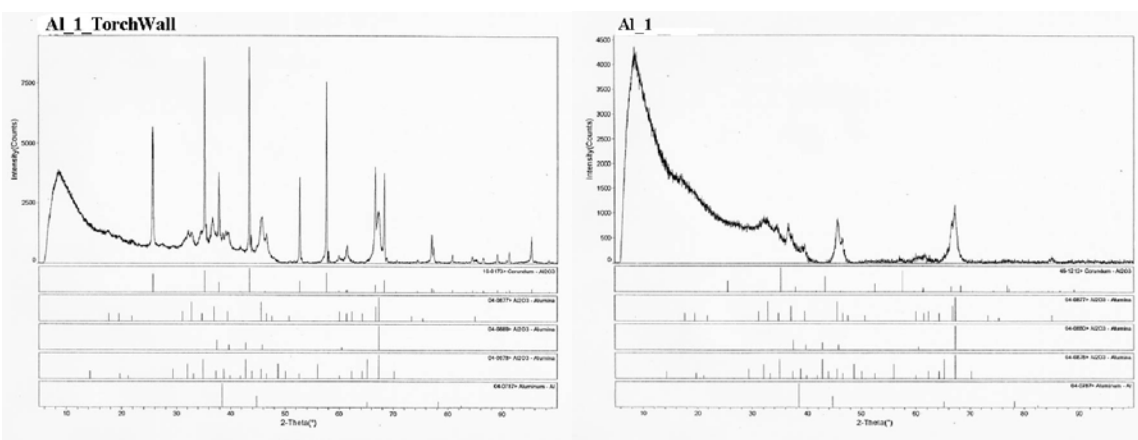

Figure 2- The phases of nano alumina particles are a function of operating conditions as shown by the difference in these two samples for which the average particle size (approx. 20 nm) were virtually identical.

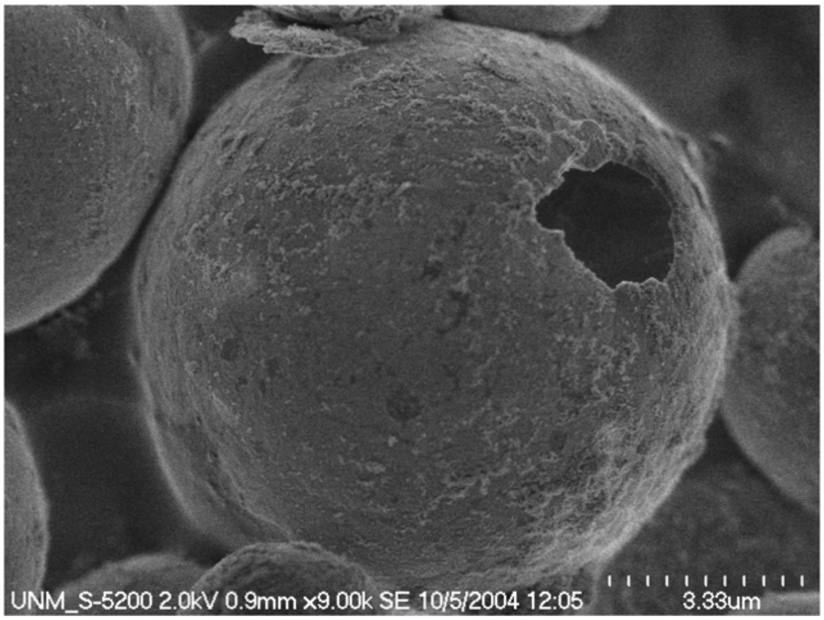

Figure 3- An example of a hollow multi cation oxide ceramic particle generated with the atmospheric pressure plasma torch.

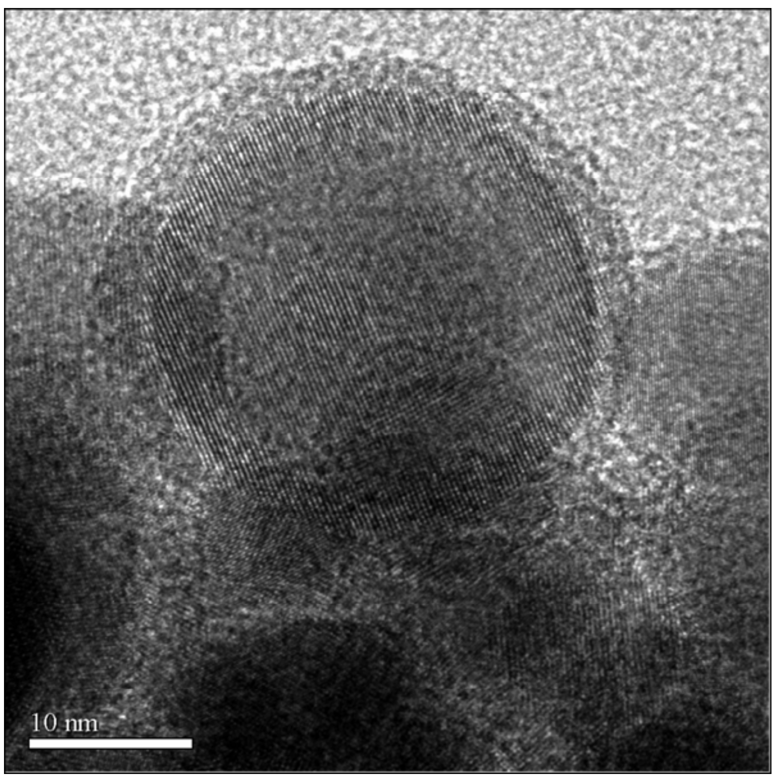

Figure 4- Under specific conditions of operation particles formed from multi-cation aerosols will form nano-scale core-shell particles, as shown.