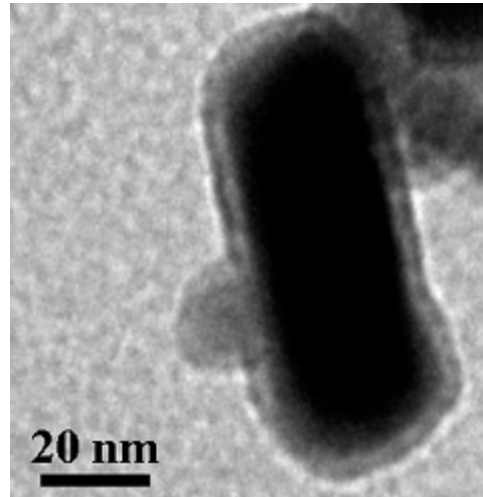


Particle ALD™

Overview: Critical materials problems exist in almost every established industry. These problems are related to thermal management, diffusional resistance characteristics, optical properties, chemical reaction characteristics, surface property mismatches, structural integrity, and electrical properties, among others. As materials are being discovered and functionalized to try to solve some of these problems, it turns out that a combination of existing materials is often the ideal solution. In many cases, a fine particle that is conformally encapsulated in one or more ultrathin layers of additional materials is exactly what is needed to solve the problem. This new class of hybrid nano-materials and their associated functionalities can be economically manufactured using a process called Particle ALD™.

Market Overview: The ultimate potential for this enabling technology is a small fraction of the coming revenues from many new nanotechnology technologies and products [per Dr. M.C. Roco's presentation in Boston on 11/7/2003 – in materials (\$300B/yr), pharmaceuticals (\$180B/yr), aerospace (\$70B/yr), electronics (\$300B/yr), and chemicals (catalysts) (\$100B/yr)].

Technology Overview: Particle ALD™ makes use of chemically bonded nanocoatings on ultrafine particles coated using a fluidized bed reactor (ALD-FBR). This provides unparalleled control relative to conventional coating processes such as Wet Solution Chemistry, Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), and Plasma-enhanced Chemical Vapor Deposition (PE-CVD). The control of Particle ALD™ will allow for the manufacture of nanocomposite materials never before produced. The conventional processes do not allow conformal atomic layer growth control over the coatings on individual primary ultra-fine particles. Also, they are line of sight dependent and do not allow true chemically bonded coatings on the surfaces. In Particle ALD™, none of these restrictions apply.



As an example of the power of Particle ALD™, nanosized zirconia powder was coated in a fluidized bed reactor with ~5 nm of alumina. The TEM image shown demonstrates the uniformity of the coating on all the particles. The crystalline ZrO₂ appears black and the amorphous Al₂O₃ coating appears gray in the TEM image. This makes it easy to discern the core zirconia particle from the alumina nanocoating. Also, this image shows a 10 nm spherical zirconia particle with the same thickness of alumina coating. Based on the sharp edges shown in the image, these particles are overlapping on the TEM substrate and are not aggregated together.

Particle ALD™ will have a significant impact in the surface modification of submicron materials. The most common competing commercial technology, CVD, will not be able to coat individual submicron particles. Particle ALD™ will also have a significant impact in applications where a very thin film (on the order of a few nanometers or less) is needed. With CVD, it is very difficult to control and get uniform films of less than a few hundred nanometers.

