Coating Powders, Pellets, and Small 3D Objects with PVD

Most thin-film deposition processes are designed with flat substrates in mind. Wafers, slides and foils present stable surfaces that face the deposition sources directly. In these applications, the science is well understood, the equipment is well established, and the results are predictable. However, a growing number of research and industrial applications involve powders, catalyst pellets and small, irregularly shaped components, where achieving a uniform coating is far more challenging.

Conventional PVD systems are typically not designed for such substrates. Particles exposed to the deposition source receive a coating, while those buried beneath remain partially coated or untouched. The result is uneven film thickness, poor surface coverage and limited process repeatability. This challenge directly affects applications ranging from catalysis, plasmonics, batteries and the emerging field of functional metamaterials creating demand for deposition systems specifically designed for complex geometries.

Why Coating Particles and Small Objects Is Harder Than It Looks

PVD is a line-of-sight process. Before deposition surfaces are normally treated with an argon glow discharge plasma to remove any adsorbed species and free up surface bonds. This allows chemical bonding of the incoming sputtered material. PVD is a high purity chemical free process. However, any surface which is not in direct view of the source will not be coated [1]. For a flat substrate, this is rarely a problem. For a container of powder particles, it is quite a different challenge. The particles at the top of the pile see the source, the rest do not. Static deposition onto a powder bed produces a coating that is essentially a thin coating on the surface layer with uncoated material underneath.

Prior research has documented four main approaches to solving this problem: rotating cylinders, rotating tilted bowls, vibrating bowls, and dusty plasma agitation. Each of these works by keeping the particles in motion during deposition so that all faces are progressively exposed to the incoming flux. The vibrating bowl approach has proven effective for particles in the nanometre to micron size range and has been used to deposit both metallic and metal oxide thin films reproducibly.

What Changes When You Get the Process Right

When particles are kept in continuous motion throughout deposition, the coverage problem resolves itself. Each particle progressively rotates through the deposition flux, exposing each face in turn. The result is a coating that is genuinely uniform across the particle surface not just on the top layer of the batch.

Work on platinum-coated carbon powders for fuel cell applications demonstrated directly that static sputtering produced badly uneven coverage and poor electrochemical output, whereas vibrated powders with effective agitation yielded consistent platinum distribution and significantly higher cell performance [2].

Comparative testing showed that sputtering without vibration deposited platinum only onto the surface layer of the carbon powder in the container, while vibration without effective agitation amplification still produced uneven distribution proper agitation was necessary to achieve the uniform coating that translated into superior fuel cell output. This is not a minor process detail. The uniformity of the catalyst coating on each particle directly determines the active surface area available for the electrochemical reaction, and therefore the efficiency of the device. Non-uniform coatings mean wasted precious metal, lower performance, and results that cannot be reproduced between batches [2].

Applications Where This Matters Most

Catalysis and Electrochemistry

The most active area of development for PVD-coated particles is catalyst synthesis for fuel cells and electrolysers. Platinum nanoparticles are widely used as catalysts in proton exchange membrane fuel cells, and sputter deposition has emerged as a promising alternative to conventional wet chemistry for nanoparticle synthesis offering a process free of contaminant oxygen, capping agents, and chemical precursors [2].

PVD sputtering can be used to disperse a catalyst directly onto the outer surface of a support powder to form a supported catalyst, with support particles ranging from nanoscale to a few microns in diameter, including metal oxides such as titanium oxide, zirconium oxide, and tin oxide[3].This is particularly relevant for membrane electrode assembly (MEA) catalyst layers, where the activity and distribution of the catalyst on the support directly determines device efficiency [3].

For green hydrogen production via PEM electrolysis, iridium-based catalysts are currently the benchmark for the oxygen evolution reaction, but iridium is scarce and expensive. Achieving uniform, thin PVD coatings on suitable support powders allows researchers to maximise the catalytic surface area per gram of iridium, which is a key target in both academic and industrial research programmes [3].

Energy Storage

Battery electrode performance depends not only on the active material, but on how charge is transported to and from it. Metal coatings applied to electrode powders can improve electronic conductivity, reduce interfacial resistance, and enhance cycling stability particularly in advanced cathode materials for lithium-ion batteries.

The global PVD coatings market is growing substantially, driven by demand for durable, high-performance coatings that conventional wet chemistry cannot easily replicate[4]. For electrode powders, a solvent-free vacuum coating approach eliminates many of the compatibility problems that arise with slurry-based wet coating: no binder decomposition, no solvent residues, and no drying shrinkage that can disrupt coating uniformity [1]

Pharmaceuticals

Coated pellets are a well-established dosage form in oral drug delivery, where the coating layer controls how quickly the active ingredient is released after ingestion. Polymer film thickness on coated drug pellets has a direct and well-characterised influence on release kinetics and controlling that thickness precisely is essential for achieving a predictable therapeutic effect [5].

PVD offers an inorganic, solvent-free alternative to conventional film-coating approaches relevant where the substrate is moisture-sensitive, where solvent residues are undesirable, or where an exceptionally thin, conformal inorganic layer is required. The precise mass loading control achievable with in-situ quartz crystal microbalance monitoring is well-suited to this kind of work [6].

Coating Small 3D Objects

Small 3D-printed and machined components increasingly need functional surface coatings for conductivity, corrosion resistance, wear resistance, or optical properties that their base material cannot provide. PVD allows coating in a wide range of metals and alloys including zirconium, chromium, nickel, titanium, gold, and their nitrides and oxides, and is not restricted to the material sets available from conventional electroplating [7].

Recent advances in sputtering technology have focused on improving target materials and integrating sputtering with other deposition techniques to handle complex substrate geometries [1]. Successful coatings have been achieved on features as small as 2 mm in diameter and 5 mm in depth, though internal cavities continue to present challenges that require careful fixturing and process design [7].

The Nikalyte NL-Powder Coating System

Nikalyte's NL-Powder Coating System (NL-PCS) was designed specifically for this class of application. It is a compact vacuum deposition system built around a vibratory bowl a fluidiser that keeps powders and pellets in continuous motion throughout the entire deposition process [6].The vibratory action ensures that all particle surfaces are progressively exposed to the incoming flux from the deposition source. The result is a uniform, repeatable coating across the entire batch, not just the surface layer.

Key specifications:

- The system is available in three configurations PCS100, PCS250, and PCS400 with bowl capacities of 0.15 litres, 0.5 litres, and 2 litres respectively. Each configuration supports two to five deposition sources depending on the chamber size, allowing for multi-material or co-deposition processes. Source types include magnetron sputter sources, nanoparticle sources, ion sources, and RF atom sources[6].
- An in-situ quartz crystal microbalance (QCM) provides real-time monitoring of mass loading throughout the run. This is what separates a production-quality result from a guess: instead of inferring coating thickness from process time and target power, you have a direct measurement of how much material has been deposited. Every run is logged automatically through Nikalyte's SPECTRUM control software, and recipes can

be saved and recalled for full reproducibility [6].

- Typical coating materials include platinum (Pt), iridium oxide (Ir_2O_3), copper oxide (CuO), ruthenium (Ru), nickel (Ni), nickel oxide (NiO), and a wide range of other inorganic materials [6].
- In-situ plasma cleaning is available prior to deposition, removing surface contamination and improving adhesion of the applied coating [6].
- The process is entirely chemical-free. No solvents, no precursors, no binders, no waste streams to manage. The only inputs are high-purity metal targets and, for reactive deposition, process gases. This makes the NL-PCS compatible with clean-room-adjacent environments and with applications where solvent contamination would be damaging including pharmaceutical and high-purity catalyst work [8].

Choosing the Right Configuration

Matching the system to your application comes down to three questions:

1. **How much material do you need to coat per run?** The PCS100 is suited to small research batches where you are screening materials or optimising process conditions. The PCS400 handles larger quantities where you are producing catalyst powders or electrode materials at a scale closer to pilot production [6].
2. **How many coating materials do you need in a single process?** Multi-source configurations allow sequential or co-deposition from different targets relevant for alloy coatings, core-shell nanoparticle structures, or layered catalyst architectures.
3. **How precisely do you need to control mass loading?** For catalyst applications where precious metal loading directly determines both performance and cost, QCM monitoring is critical. For applications where approximate thickness is sufficient, simpler process control may be adequate. [2]

If you are coating small 3D objects rather than bulk powders, the same chamber is used, but the fixturing approach changes individual parts are mounted so that they can be repositioned or rotated during deposition to maximise coverage across complex geometry. [7]

What to Expect from High-Quality Powder Coating

A uniform PVD coating on a catalyst powder or electrode material should show:

- Consistent particle-by-particle coverage when examined by electron microscopy not thick deposits on some particles and bare surfaces on others.
- Reproducible mass loading from run to run, confirmed by QCM data and verified by techniques such as ICP-MS or TGA if the application requires independent confirmation of total metal content [6].
- Electrochemical activity that scales with loading, rather than showing diminishing returns from inactive or shadowed regions. For fuel cell or electrolyser catalysts, this is the most direct performance test [2].

- No contamination from solvents, surfactants, or chemical precursors that would need to be removed by post-processing steps such as calcination or washing [2]

These are the characteristics that distinguish a PVD-coated powder from one produced by incipient wetness impregnation, electroless deposition, or other wet chemical routes [8]

Conclusion

Coating powders, pellets, and small 3D objects with PVD is technically demanding but the demand exists because the results are worth it. Uniform, conformal, chemical-free inorganic coatings with precise mass loading control are simply not achievable by conventional wet chemistry, and the applications that require them from fuel cell catalysts to pharmaceutical pellets to functional coatings on printed components are growing [1],[4]

Nikalyte's NL-Powder Coating System addresses this directly, with a purpose-built vibratory bowl design, QCM monitoring, multi-source capability, and in-situ plasma cleaning. If you are working on a catalyst development programme, an electrode material study, or any application where powder coating quality is limiting your results.

Contact Nikalyte team about whether the NL-PCS fits your process or download the NL-PCS brochure for full technical specifications.

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